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REVIEW

Interdisciplinary education and skills driving sustainable innovation in applied biosciences

Educación y habilidades interdisciplinarias que impulsan la innovación sostenible en biociencias aplicadas

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ABSTRACT

Introduction: interdisciplinary education has emerged as a strategic approach to enhance competencies in applied biosciences, fostering sustainable innovation in professional training.
Objective: to analyze pedagogical, technological, and curricular strategies that promote integral learning in bioscience programs, based on recent literature.
Method: an exploratory review of scientific publications from 2020 to 2025 was conducted, structured according to the PRISMA methodology, with a focus on educational approaches in biological and environmental sciences.
Results: active methodologies—such as problem-based learning, the use of information and communication technologies (ICTs), and the integration of Sustainable Development Goals (SDGs)—strengthened critical skills including analytical thinking, multidisciplinary collaboration, and socio-environmental awareness. Integrated curricula and collaborative projects proved effective in connecting theoretical knowledge with real-world problem solving, reinforcing both academic and social relevance. However, structural limitations persisted, including curricular rigidity, limited teacher training in interdisciplinary methods, and the digital divide.
Conclusions: despite these challenges, the incorporation of emerging technologies—such as artificial intelligence and virtual learning environments—offers promising pathways to transform education into more flexible, inclusive, and sustainable models. Interdisciplinary education not only drives innovation in applied biosciences but also responds to the scientific, technological, and environmental demands of the 21st century.

Keywords: Active Learning; Interdisciplinary Education; Professional Competencies; Biosciences; Educational Technology.

RESUMEN

Introducción: la educación interdisciplinaria ha emergido como una estrategia clave para fortalecer competencias en biociencias aplicadas, promoviendo la innovación sostenible en la formación profesional.

Objetivo: analizar las estrategias pedagógicas, tecnológicas y curriculares que favorecen el aprendizaje integral en programas de biociencias, a partir de una revisión de literatura reciente.
Método: se realizó una revisión exploratoria de publicaciones científicas entre 2020 y 2025, estructurada según la metodología PRISMA, con énfasis en enfoques educativos aplicados a las ciencias biológicas y ambientales.
Resultados: las metodologías activas—como el aprendizaje basado en problemas, el uso de tecnologías de la información y comunicación (TIC), y la integración de los Objetivos de Desarrollo Sostenible (ODS)—potenciaron habilidades críticas como el pensamiento analítico, la colaboración multidisciplinaria y la conciencia socioambiental. Los planes de estudio integrados y los proyectos colaborativos demostraron ser eficaces para vincular el conocimiento teórico con la resolución de problemas reales, fortaleciendo la pertinencia académica y social. Sin embargo, persistieron limitaciones estructurales como la rigidez curricular, la escasa formación docente en enfoques interdisciplinarios y la brecha digital.
Conclusiones: a pesar de los desafíos, la incorporación de tecnologías emergentes—como la inteligencia artificial y los entornos virtuales de aprendizaje—ofrece oportunidades para transformar la educación en modelos más flexibles, inclusivos y sostenibles. La educación interdisciplinaria no solo impulsa la innovación en biociencias aplicadas, sino que también responde a los desafíos científicos, tecnológicos y ambientales del siglo XXI.

Palabras clave: Aprendizaje Activo; Educación Interdisciplinaria; Competencias Profesionales; Biociencias; Tecnología Educativa.

INTRODUCTION

The advancement of applied biosciences has enabled a deeper understanding of the biological processes that sustain life, along with their sustainable and innovative applications in medicine, biotechnology, and the environment. Nevertheless, an educational approach that promotes the integration of knowledge from diverse disciplines is required, with interdisciplinarity serving as a key strategy to strengthen learning.

Biosciences are regarded as an inherently interdisciplinary field due to their continuous innovation and evolution over time.(1) This approach integrates knowledge from biology, engineering, chemistry, and social sciences, thereby contributing to more comprehensive solutions. Incorporating interdisciplinarity into education within the biological sciences involves profound collaboration that fosters the exchange and joint construction of knowledge.(1)

In education, interdisciplinarity is more than a teaching methodology; today, it is a necessity for training future professionals capable of addressing the challenges of an interconnected and constantly changing world. In this sense, the implementation of technology as a vital resource with the potential to revolutionize teaching processes has facilitated access to more dynamic and interactive educational experiences. Technology has thus become an essential tool in an increasingly connected society, making the development of digital competence an indispensable skill.(2)

A fundamental aspect of the impact of interdisciplinary collaboration in educational research lies in its potential to formulate new questions and give rise to new areas of academic exploration. In addition to fostering skills such as critical thinking and the ability to work in multidisciplinary teams, both highly valued in today's labor market it is important to highlight that interdisciplinarity originated within research as a means of addressing complex problems that inevitably required the integration of concepts and approaches from various disciplines.(3)

Interdisciplinary approaches developed within the biological sciences have incorporated project-based learning strategies, aimed at enriching the understanding of key concepts and fostering the development of critical thinking through connections with other fields of knowledge. This educational strategy has been consolidated as one that enhances motivation, concept acquisition, critical thinking, and the integration of content from different disciplines. Moreover, the use of cross-disciplinary ideas contributes both to information retention and to its practical application, facilitating the construction of more enduring learning.(4)

Therefore, in the field of educational innovation, the use of technology in learning environments provides educators with the ability to design and organize content pedagogically. This not only strengthens their own expertise but also enhances student learning by promoting more effective academic activities. At the same time, current social, cultural, technological, and productive transformations demand high-quality teacher training focused on interdisciplinary, competency-based education. This integration of essential knowledge is closely linked to interdisciplinarity and biosciences.(5)

The primary objective of this review was to synthesize and critically evaluate the available evidence on how interdisciplinary education contributes to the development of essential competencies required to foster sustainable innovation in the field of applied biosciences. This involved integrating studies that examined pedagogical models, technological strategies, and curricular approaches implemented in diverse educational contexts. By consolidating these findings, the review aimed to identify both successful practices and persistent challenges, thereby offering a comprehensive understanding of the role of interdisciplinarity in advancing innovation and sustainability within bioscience education.

METHOD

This study followed a Systematic Literature Review (SLR) approach grounded in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses PRISMA statement to ensure methodological rigor, transparency, and reproducibility. The review protocol was defined a priori, specifying the research question, inclusion/exclusion criteria, search strategy, screening procedures, and synthesis methods.

1. Review Protocol and Research Question

The SLR was guided by the following research question:

RQ: how does interdisciplinary education contribute to the development of competencies that promote sustainable innovation in applied biosciences in higher education?

The protocol was structured according to PRISMA standards and adhered to the methodological requirements for high-impact journals in education and applied sciences. The protocol was not registered in PROSPERO due to its focus on educational research, but it was internally validated by the research team.

2. Eligibility Criteria

Eligibility criteria were defined using the PICOS framework (Population, Intervention, Context, Outcomes, Study Type) to strengthen methodological clarity:

Population (P)

Students, educators, and higher education institutions involved in biosciences, STEAM, environmental sciences, biotechnology, and related fields.

Intervention (I)

Pedagogical strategies, curricular models, technological tools, and interdisciplinary approaches applied to teaching and learning.

Context (C)

Higher education institutions and pre-university educational settings within the biological, environmental, and applied bioscience domains.

Outcomes (O)

Development of competencies related to innovation, sustainability, critical thinking, interdisciplinary integration, and digital/technological skills.

Study Types (S)

Peer-reviewed empirical studies, qualitative studies, mixed-methods research, theoretical analyses, and systematic/bibliographic reviews published from January 2020 to March 2025.

Inclusion Criteria

- Peer-reviewed publications in English or Spanish.
- Explicit focus on interdisciplinarity in educational settings.
- Studies addressing biosciences, STEAM, biological sciences, or related applied sciences.
- Articles linking educational outcomes with innovation, competencies, or sustainability.
- Availability of full text.

Exclusion Criteria

- Non-peer-reviewed materials (editorials, blogs, opinion papers, conference abstracts).
- Studies unrelated to education or interdisciplinarity.
- Articles lacking methodological transparency or conceptual alignment.
- Duplicate records.

3. Search Strategy

A comprehensive search was conducted between January and March 2025 across the following databases:

- Scopus

- ScienceDirect
- Web of Science
- PubMed
- Google Scholar
- Redalyc
- SciELO

Search strings were adapted to each database to ensure sensitivity and specificity. The core boolean structure included:

("interdisciplinary education" OR "cross-disciplinary learning" OR "transdisciplinary") AND ("biosciences" OR "biological sciences" OR "applied sciences" OR "environmental sciences" OR STEAM) and ("sustainability" OR "innovation" OR "competencies" OR "active learning" OR "curriculum design" OR "educational technology").

Manual backward and forward citation tracking (snowballing) was conducted to identify additional relevant studies not captured in initial searches. The search was last updated on March 15, 2025.

4. Screening and Study Selection

All retrieved records were managed using Rayyan® to detect duplicates, organize citations, and facilitate independent reviewer screening. The selection occurred in three stages:

1. Identification: Removal of duplicates and preliminary filtering.
2. Screening: Title and abstract assessment against inclusion criteria.
3. Eligibility: Full-text review for final inclusion.

Two reviewers independently evaluated each article. Disagreements were resolved by consensus or adjudication by a third reviewer. Inter-rater reliability was assessed through Cohen's Kappa (κ = 0,82; 95 % CI: 0,76–0,88), indicating substantial agreement.

A total of 112 records were retrieved, 74 remained after duplicate removal, 38 were eligible for full-text review, and 26 were included in the final synthesis.

A detailed PRISMA flow diagram is presented in figure 1 of the manuscript.

5. Data Extraction Process

A structured data extraction matrix was developed to ensure consistency. For each study, the following information was extracted:

- Author(s), year, country
- Study type and methodological design
- Educational context and population
- Description of interdisciplinary intervention/model
- Reported competencies (innovation, sustainability, critical thinking, digital skills, etc.)
- Pedagogical/technological tools used
- Key findings and implications
- Limitations reported by the authors

6. Quality Assessment and Risk of Bias

The methodological quality of the included studies was assessed using instruments aligned with study type:

- CASP Qualitative Checklist for qualitative studies
- MMAT (Mixed Methods Appraisal Tool) for mixed-methods designs
- JBI Critical Appraisal Tools for systematic reviews and descriptive studies

Each study received a rating (Low, Medium, High quality). Only studies rated Medium or High were included in the final synthesis to preserve methodological rigor.

Risk of bias was evaluated in relation to:

- Sampling strategies
- Data collection procedures
- Analytical consistency
- Researcher reflexivity
- Transparency in reporting methods and findings

No study was excluded exclusively due to bias risk, but results were interpreted considering these assessments.

7. Data Synthesis

Given the heterogeneity in methodologies and contexts, a thematic synthesis approach was applied. This involved:

1. Generating initial descriptive codes from extracted data.
2. Grouping codes into analytical categories, such as:
    - Interdisciplinary pedagogical models
    - Technological integration (ICT, AI, virtual labs)
    - Sustainability-oriented educational strategies
    - Competency development frameworks
3. Developing higher order themes, which served as the basis for the Results and Discussion sections.

This interpretive synthesis enabled identifying recurring patterns, contextual differences, and emerging trends in interdisciplinary bioscience education.

8. Ethical Considerations

As the review was based solely on published academic literature, ethical approval was not required. All studies were cited and handled according to international academic integrity standards.

Interdisciplinary strategy

Interdisciplinarity in education is a valuable tool that enables students to establish connections among different disciplines, formulate responses to complex problems, and organize learning in a more coherent and integrated manner. This approach fosters the integration of knowledge, skills, and values required for effective professional performance, proving especially useful when grounded in a solid theoretical foundation. [6]

Currently, advances in biosciences emphasize that the essence of life lies in a continuous learning process present at all structural levels. Therefore, the traditional epistemological division between basic and applied sciences becomes increasingly unnecessary, given the growing evidence of unexpected consequences that may arise from inadequate genetic manipulation.[6]

Educational and Pedagogical Models Focused on Interdisciplinarity

The application of interdisciplinary approaches in education, particularly in the sciences, enhances problem comprehension, stimulates the identification of cross-disciplinary connections, and promotes critical thinking. It also enables students to incorporate knowledge acquired beyond the traditional classroom environment more effectively. One of the strategies implemented to foster this integration has been the use of integrated science programs, which combine content from two or more disciplines to expand student learning.[7]

Furthermore, interdisciplinarity in the classroom involves applying concepts and methods from different disciplines to address complex issues, foster critical and creative thinking, and achieve a more efficient understanding of knowledge. In this context, the *Integrative Knowledge Project (Proyecto Integrador de Saberes, PIS)* has emerged as an educational strategy that bridges teaching, research, and community engagement.[8]

Table 1. Advantages of Interdisciplinary Educational Models in the Teaching-Learning Process

Advantage	Description
Use of technology in education (Barbera et al.[28])	Promotes the effective use of ICT as didactic resources.
Integration in content study (Calderón et al.[20])	Fosters more comprehensive and contextualized learning.
Teamwork development (Bell et al.[11])	Trains professionals capable of collaborating in multidisciplinary environments.
Problem-solving across multiple disciplines (Santaolalla et al.[24])	Enables addressing complex challenges with contributions from diverse scientific fields.
Enrichment of academic content (Orellana[19])	Interdisciplinary approaches allow for broader and deeper understanding.
Increased motivation and critical engagement (Cuncachi & Ochoa[6])	Enhances student interest and stimulates critical-reflective thinking.
Better management of academic time (Mora[11])	Avoids unnecessary repetitions, making the teaching-learning process more efficient.

Interdisciplinary approaches positively influence learning by linking scientific knowledge with real-life situations, thereby strengthening analytical skills, enhancing interpretation, and fostering decision-making for transforming reality. Their impact on knowledge acquisition and assimilation has been recognized in educational policies aimed at improving quality through diverse strategies that support effective curriculum implementation. Moreover, interdisciplinarity contributes to the development of professional competencies by integrating knowledge, skills, attitudes, and values required for successful workplace performance.[9]

Key advantages of interdisciplinary pedagogical approaches, particularly their ability to integrate diverse forms of knowledge, are summarized in table 1.

Problem-Based Learning and ICT

Problem-based learning supported by information and communication technologies (ICT) is considered an effective strategy to strengthen scientific competencies, leading to efficient learning outcomes and a more positive educational environment, as shown in experiences from Uruguay. Similarly, the use of statistical projects with an interdisciplinary approach shares the objective of addressing and investigating issues by integrating knowledge and methods from diverse scientific disciplines.[10]

Importance of Innovation and Sustainability in Applied Biosciences

International declarations have long emphasized the importance of embedding sustainable development into curricula, fostering inter- and transdisciplinary research, and promoting social awareness. In this context, the United Nations established the 17 Sustainable Development Goals (SDGs), positioning higher education as a strategic axis for their implementation. These goals aim to strengthen quality education that, through the use of appropriate tools and resources, transforms the way young people think and act.[11]

Today, due to the rapid pace of technological advancements and constant societal change, sustainability has become an essential component of education. This has required institutions to quickly adapt to new teaching models, representing a significant challenge for all stakeholders. Within this framework, artificial intelligence (AI) emerges as a powerful tool to overcome challenges associated with the implementation of sustainable and efficient education.[1]

Emerging Technologies in Interdisciplinary Learning of Applied Biosciences

The teaching and learning of science in the classroom increasingly incorporate technology, positioning students as active participants in their own learning while the teacher assumes the role of facilitator. This approach promotes the development of scientific competencies through interdisciplinarity. To achieve this, it is necessary to move beyond traditional pedagogical models based on rote memorization and adopt methodologies that encourage students to explore, investigate, and construct their own knowledge.[12]

The incorporation of artificial intelligence in education is revolutionizing teaching and learning by allowing educational content to be adapted and offering students personalized learning experiences. At the same time, it equips teachers with tools to monitor academic performance in greater detail. Consequently, AI is not only reshaping pedagogical strategies but also transforming traditional teaching by adapting to the needs of different areas of education.[13]

In addition, more dynamic methodologies are being implemented in molecular genetics education, such as the use of virtual laboratories and simulations, as traditional approaches are often insufficient for mastering complex content. In health sciences, simulations have proven valuable by enabling students to practice laboratory techniques, procedures, and even surgical interventions without relying on living organisms. This resource has enhanced training outcomes and significantly improved learning processes.[14]

One of the main advantages of technology in science education is its ability to drive educational change, allowing for the revision and improvement of classroom practices. Unlike traditional content-centered methods, multimedia computing and network connectivity have expanded opportunities for communication and knowledge exchange, thus broadening the scope of learning.[15]

Considering that new generations are digital natives, the incorporation of video games into educational settings has emerged as an innovative didactic strategy that fosters new forms of learning. Educational video games have gained significant support due to their ability to capture student attention, increase motivation, and enhance both individual and group learning experiences in the classroom.[16]

Current and Future Challenges

Lack of teachers with interdisciplinary training. Many teachers lack the resources and preparation needed to design and implement integrative pedagogical approaches. They also face limitations in research methodology training, creating obstacles for managing high-quality research projects.[17]

Teacher leadership is therefore essential. Designing strategies that promote interdisciplinary collaboration in scientific research is crucial for enriching the exchange of knowledge among educators. Regardless of their area of expertise, all departments and disciplines can contribute knowledge and experiences, strengthening both the development and quality of research projects.

Limited access to technological resources. Inequalities in access to technology and inadequate infrastructure hinder the effective use of digital resources in education. Teachers must carefully select technological tools when designing learning experiences to maximize their impact.[18]

The digital divide in education is significant: students with limited access to technology are at a disadvantage compared to those with more resources. Lack of digital tools and online learning opportunities restricts access to updated information, hampers the development of digital competencies, and limits active participation in an increasingly digital society.

Effective integration of sustainability in biosciences

Aligning bioscience education with the SDGs requires implementing actions that foster sustainability-related competencies to address human needs effectively.[19] Virtual learning environments can support this by raising awareness of environmental protection and climate change mitigation. Interactive modules allow students to develop practical sustainability-oriented skills. This approach not only builds awareness but also addresses the educational impact of virtual environments in environmental education.

In Ecuador, the Ministry of Education has incorporated pedagogical strategies based on active methodologies and collaborative work into its curriculum, following the *Education 2030 Agenda*. In higher education, the implementation of a sustainable curriculum has integrated the principles of sustainable development across all components of academic programs. Its purpose is to combine theoretical knowledge with practical application while considering social, economic, and environmental impacts.

RESULTS

This study analyzed various interdisciplinary and pedagogical approaches aimed at developing competencies in applied biosciences, with particular emphasis on their relationship with educational innovation and sustainability. The collected information was organized into three tables in order to categorize and present the findings in a structured manner.

Characteristics of the Studies

The articles included in this review were published between 2020 and 2025. Most of the selected works were review articles (n = 26), followed by bibliographic reviews primarily focused on the impact of interdisciplinary education on the development of competencies and sustainable innovation in applied sciences training. Regarding methodological design, qualitative studies predominated.

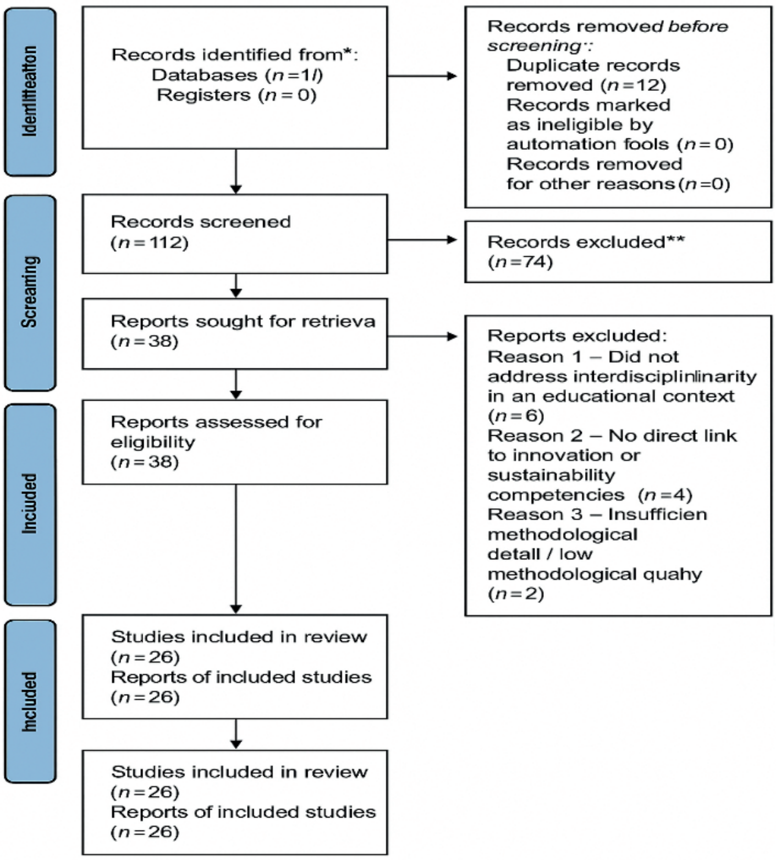

Figure 1. Flowchart of the article selection process by PRISMA

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Table 2. Study of various interdisciplinary approaches

Reference	Interdisciplinary approach	Methodology	Study objective	Competence
Calderón C, Jaramillo C, Isch É. [20]	Integrated curriculum for sustainable development and global citizenship	Qualitative (grounded theory)	Sustainable development and curriculum management	Global citizenship and social responsibility
Bell R, Orozco I, Lema B.[11]	Joint research centers and interdisciplinary projects	Empirical review	Interdisciplinary research through collaborative strategies	Teamwork and collaboration
Castro A, García M.[5]	SDGs integrated in STEAM curriculum	Report and systematic review	Competences in sustainability within engineering	Systemic and critical thinking

Table 3. Pedagogical approaches and their relation to innovation and sustainability

Pedagogical approach	Relation to innovation	Contribution to sustainability
Problem-Based Learning (PBL) (Rentería et al.[27])	Promotes critical thinking, creative problem-solving, and active learning.	Encourages the analysis of real-world issues, fostering sustainable proposals from multiple areas.
Use of Information and Communication Technologies (ICT) (Barbera et al.[28])	Facilitates interactive and adaptive learning environments with access to digital resources.	Reduces paper usage and enables continuous distance learning, lowering the ecological footprint.
Interdisciplinary teaching (Mora[11])	Integrates knowledge from diverse disciplines to generate innovative solutions.	Enables a holistic approach to the SDGs, fostering sustainable development across different fields of knowledge.
Collaborative projects (Santaolalla et al.[24])	Strengthens teamwork, effective communication, and collective innovation such as in PIS.	Promotes social and environmental responsibility in real learning contexts.
Curriculum integration of SDGs (Castro & García[5])	Updates educational content aligned with global challenges.	Prepares students to act consciously and sustainably in their professions.

Interdisciplinary Integration Experiences

Table 2 analyzes different experiences of applied interdisciplinary integration, highlighting the implementation of an integrated curriculum oriented toward sustainable development and global citizenship, using a qualitative methodology based on grounded theory.[20] It also emphasizes the incorporation of the Sustainable Development Goals (SDGs) into the STEAM curriculum to strengthen competencies such as systemic and critical thinking in engineering.[5]

Regarding the interdisciplinary approach and its link to competency development in applied biosciences, several recent studies highlight innovative educational strategies. On the one hand, implementing an integrated curriculum oriented toward sustainable development and global citizenship through a qualitative grounded theory approach helps strengthen competencies. On the other hand, analyzing the effectiveness of joint research centers and interdisciplinary projects through empirical review demonstrates the reinforcement of professional skills.

The incorporation of technologies such as artificial intelligence, visualization tools, computing, the internet, open data repositories, and geographic information systems into educational processes can further enhance students' competencies, attitudes, and values, optimizing their training in sustainable development and advancing the achievement of the SDGs by 2030.[21]

Pedagogical Approach, Innovation, and Sustainability

At present, interdisciplinary approaches have been adopted to integrate scientific and academic tasks. These proposals require a reorganization of the epistemological frameworks and methods inherent to each discipline when applied. Therefore, implementing an interdisciplinary model within pedagogical management entails a transformation in the teacher's role, conceived as part of a social construction process in which participants exchange knowledge during the educational process.

Table 3 describes the main pedagogical approaches identified and their direct relationship with educational innovation and sustainability. For example, problem-based learning promotes critical thinking and creative problem-solving in relation to generating sustainable solutions. Likewise, the use of information and communication technologies facilitates adaptive learning environments that contribute to reducing the ecological footprint through distance education.

In addition, systematic reports and reviews on the incorporation of the SDGs into curricula highlight the development of competencies related to sustainability, systemic thinking, and critical reasoning, particularly in the field of engineering. These findings demonstrate that interdisciplinarity not only transforms educational processes but also drives the development of key competencies to address current challenges in biosciences and other areas of knowledge.

Table 4. Interdisciplinary strategies for the development of competencies in applied biosciences

Article	Methodology	Competencies in Applied Biosciences	Results
Education and sustainability: Interdisciplinary strategies for the training of environmentally responsible citizens in diverse educational contexts (Cuncachi & Ochoa[6])	Interdisciplinary approach in environmental education	Ecological awareness, socio-environmental responsibility, and collaborative work	Training environmentally responsible citizens through the integration of bioscientific disciplines
Development of transversal competencies and SDGs through design thinking (Mera et al.[21])	University activity with design thinking	Integration of SDGs and transversal competencies in biosciences	Students report development beyond expectations, with high levels of innovation
Development of STEM competencies through the programming of self-organization models (Orozco et al.[22])	Computational project integrating physical-biological modeling	Mathematical modeling, systemic thinking, applied programming to biology	Encourages systems thinking, complex reasoning, and programming skills

Although significant theoretical advances have been achieved in interdisciplinarity, its practical application in the classroom continues to face structural obstacles. This is largely due to the fragmented organization of disciplines, resulting from the rigidity of curricula, as well as the lack of adequate teacher training to efficiently integrate knowledge. In this context, personalized learning has been considered, which consists of adapting teaching to the characteristics and needs of each student, supported by educational technology that facilitates more flexible and adaptable methods.

The lack of interdisciplinary approaches and insufficient teacher preparation restrict the scope and effectiveness of educational initiatives. This underscores the urgency of rethinking and strengthening current strategies, since their proper implementation facilitates the simultaneous development of multiple transversal competencies, including those that are more difficult to promote through traditional practical methods, such as innovation and creativity.

The studies analyzed (table 4) demonstrate that an interdisciplinary approach fosters the development of competencies in applied biosciences. For example, environmental education contributes to ecological awareness and socio-environmental responsibility; the integration of SDGs and transversal competencies promotes high levels of innovation in education; and the implementation of self-organization models strengthens systemic thinking and teachers' skills.

Biosciences and sustainability: curriculum integration

The incorporation of sustainability into academic programs goes beyond the inclusion of new subjects, as it implies integrating these principles into all disciplines. To achieve this, it is necessary to adopt an interdisciplinary approach that allows students to understand the relationship between environmental, social, and economic dimensions of sustainability. Likewise, it is essential that curricula include practical activities and projects that facilitate the application of theoretical content in real contexts, promoting action-oriented learning.[22]

DISCUSSION

The reviewed literature highlights that interdisciplinary education has evolved from being an innovative pedagogical approach to becoming a structural necessity in applied biosciences. Its capacity to integrate knowledge from multiple fields not only enhances student learning but also strengthens the ability of higher education institutions to respond to increasingly complex social, scientific, and environmental demands. In particular, the combination of problem-based learning, information and communication technologies, and design thinking fosters the development of higher-order competencies such as systems thinking, creativity, and ethical decision-making. These skills are indispensable for advancing sustainable innovation and ensuring that future professionals can contribute meaningfully to the achievement of the Sustainable Development Goals (SDGs).[23]

A significant outcome of interdisciplinary approaches is the establishment of meaningful connections between theory and practice. When students are exposed to real-world problems, they are encouraged to integrate scientific knowledge with social, cultural, and ethical perspectives. This not only consolidates cognitive and technical skills but also nurtures attitudes of responsibility, empathy, and global citizenship—attributes highly demanded in contemporary labor markets. Studies have also shown that collaborative and interdisciplinary projects increase academic motivation, reduce dropout rates, and foster resilience in students facing challenging learning scenarios.[6]

Moreover, the STEM and STEAM models provide fertile ground for interdisciplinarity, as they stimulate inquiry-based learning and critical reflection across diverse disciplines. These models highlight how complex problem-solving benefits from the convergence of mathematics, science, technology, engineering, and the arts, reinforcing the idea that innovation emerges most effectively at the intersection of different knowledge domains. Research such as that of Santaolalla et al.[24] demonstrates that interdisciplinary collaboration can even generate emergent behaviors comparable to those observed in natural systems, offering deeper insights into how students process and apply knowledge.

Nonetheless, the literature consistently identifies persistent barriers that hinder the effective implementation of interdisciplinarity. Structural issues such as rigid curricula, discipline-centered teaching models, and fragmented academic planning continue to restrict innovation in higher education. Equally critical is the insufficient training of educators, many of whom lack experience in interdisciplinary methodologies or the technological skills needed to integrate digital resources into their teaching practices.[25] The digital divide further exacerbates inequities, as students with limited access to technology remain at a disadvantage compared to their peers. These challenges reveal the urgency of adopting inclusive educational policies that foster equal opportunities, provide continuous teacher development, and ensure institutional support for innovation.

At the same time, the rapid expansion of digital technologies provides unprecedented opportunities. Artificial intelligence, open data repositories, and geographic information systems are transforming learning into dynamic, flexible, and personalized processes. These tools enable educators to design adaptive environments that respond to individual learning needs, enhance student autonomy, and encourage collaborative knowledge creation. Beyond the classroom, such technologies also provide access to vast networks of global knowledge, preparing students to engage in transdisciplinary research and international collaboration. However, their implementation requires robust ethical frameworks to ensure responsible use, data privacy, and the prevention of biases in educational algorithms.[17]

Another relevant aspect concerns the cultural transformation required within educational institutions. Successful interdisciplinarity cannot be reduced to methodological innovation alone; it must be embedded in the institutional mission, values, and governance structures. This means rethinking evaluation systems, academic incentives, and research agendas to reward collaboration rather than disciplinary isolation. Only through such systemic change can universities create fertile environments where interdisciplinarity thrives and contributes to long-term sustainability.

In addition, emerging pedagogical practices—such as outdoor education, design thinking, and project-based learning—demonstrate that interdisciplinarity also promotes socio-environmental awareness. By linking academic content with ecological and community challenges, these methodologies enhance students' ability to envision sustainable solutions that are both innovative and socially responsible. In this sense, interdisciplinarity is not merely an academic tool but also a transformative pathway for creating more conscious, ethical, and sustainable societies.[4,26]

Looking toward the future, interdisciplinarity in applied biosciences must not only address scientific and technological complexity but also anticipate global challenges such as climate change, food security, public health crises, and biodiversity loss. Education must prepare professionals capable of working across disciplinary and cultural boundaries, equipped with both technical expertise and humanistic perspectives. Therefore, a stronger dialogue between academia, industry, and society is essential to ensure that the competencies developed through interdisciplinary education are relevant and applicable to real-world contexts.

LIMITATIONS

Although this systematic review was conducted following PRISMA 2020 standards and applied rigorous inclusion, screening, and quality appraisal procedures, several limitations should be acknowledged. First, the review included only publications available in English and Spanish, which may have excluded relevant studies conducted in other languages and created a potential linguistic bias. Second, despite the comprehensive search strategy, the reliance on digital databases may have limited the identification of gray literature or institutional reports that could provide additional perspectives on interdisciplinary practices in applied biosciences.

Third, most of the included studies were qualitative or descriptive in nature, which restricts the ability to generalize findings or establish causal relationships between interdisciplinary approaches and competency development. Furthermore, variations in methodological quality, sample sizes, and educational contexts across studies may influence the comparability of results. Fourth, publication bias is possible, as studies reporting positive or innovative outcomes are more likely to be published than those describing challenges or unsuccessful implementations.

Finally, although the review synthesized recurring themes and patterns, the heterogeneity of pedagogical models, technologies, and curricular frameworks limited the capacity to perform a quantitative synthesis or meta-analysis. These limitations highlight the need for future research employing more robust experimental designs, standardized assessment tools, and cross-institutional analyses to deepen understanding of how interdisciplinarity contributes to innovation and sustainability in applied biosciences education.

CONCLUSIONS

Interdisciplinary education stands out as a key strategy for strengthening competencies and driving sustainable innovation in applied biosciences. The evidence indicates that methodologies such as problem-based learning, project-based learning, design thinking, and the use of digital technologies foster critical thinking, collaborative work, and socio-environmental awareness. These approaches help bridge theoretical knowledge with real-world challenges, producing professionals better prepared to contribute to the achievement of the Sustainable Development Goals (SDGs).

Nevertheless, significant barriers remain. Curriculum rigidity, fragmented academic structures, limited teacher training, and unequal access to technology continue to hinder the effective implementation of interdisciplinarity. Overcoming these obstacles requires deep institutional transformation aimed at creating flexible curricula, strengthening continuous professional development, and promoting inclusive educational policies that support innovation. Furthermore, universities must cultivate a culture that values collaboration, knowledge integration, and sustainability as fundamental components of academic life.

At the same time, the integration of advanced technological tools—such as artificial intelligence, open data repositories, and virtual learning environments—offers opportunities to build adaptive and dynamic educational models. These innovations, if implemented responsibly and ethically, can enhance learning processes, personalize training, and expand access to quality education.

In conclusion, interdisciplinary education in applied biosciences is not merely a pedagogical trend but an urgent necessity. Its adequate implementation requires both methodological and cultural change within higher education institutions. Only through systemic transformation will it be possible to develop professionals capable of combining scientific knowledge with creativity, innovation, and ecological awareness. This integration will enable the construction of sustainable, inclusive, and socially relevant educational models capable of responding to the complex scientific, technological, and environmental challenges of the 21st century.

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ETHICAL APPROVAL

As this study is a systematic literature review based exclusively on previously published academic sources, it did not require approval from an ethics committee. No human participants, animals, or sensitive personal data were involved.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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