



Developing Future Biomedical Innovators Through Challenge-Based Learning Using Breast Milk-Derived Bioactive Peptides in Cancer Research Education

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ABSTRACT

The integration of emerging biomedical research into higher education offers opportunities to develop scientific reasoning, biotechnology literacy, and innovation-oriented competencies. This study explores the potential of Challenge-Based Learning (CBL) through breast-milk-derived bioactive peptides and cancer research as an authentic context for biotechnology education. A qualitative descriptive research design is employed, involving students from biotechnology, biology, biomedical science, or related higher education programs. Data are collected through students' written reflections, group discussions, and proposed solutions developed during structured learning activities. The data are analyzed thematically to examine three dimensions: biotechnology literacy and understanding of scientific evidence, scientific reasoning and critical thinking, and biomedical innovation and responsible problem-solving. The study positions breast-milk-derived bioactive compounds as a context for examining molecular biology, evaluating experimental and clinical evidence, and understanding the translation of scientific discoveries into potential therapeutic applications. Rather than treating emerging biomedical research as established clinical practice, the learning framework emphasizes scientific accuracy, recognition of uncertainty, and ethical responsibility. This study is expected to contribute to biotechnology education by providing insights into the use of authentic biomedical challenges to support interdisciplinary learning and responsible innovation. The findings may inform the design of educational activities that connect scientific knowledge with contemporary biomedical research without requiring specialized laboratory facilities.

Keywords: Challenge-Based Learning; Biotechnology Education; Breast-Milk-Derived Bioactive Peptides; Cancer Research Education; Scientific Reasoning; Biomedical Innovation

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INTRODUCTION

The rapid advancement of biotechnology and biomedical science has created new demands for higher education, particularly in preparing students to address complex health challenges through scientific reasoning, interdisciplinary collaboration, and innovation (Javaid et al., 2023). Emerging therapeutic approaches increasingly depend on the integration of molecular biology, biochemistry, genetics, and translational research. Consequently, biotechnology education must extend beyond the transmission of established scientific knowledge to develop students' capacity to interpret research evidence, formulate hypotheses, evaluate potential applications, and communicate scientifically justified solutions. However, conventional instructional approaches

may provide limited opportunities for students to engage with authentic biomedical problems and understand how scientific discoveries progress from fundamental research toward potential clinical applications. This challenge highlights the need for pedagogical approaches that connect disciplinary knowledge with real-world scientific problems and the competencies required for biomedical innovation.

Challenge-Based Learning (CBL) offers a promising approach to addressing this educational challenge (Perzolli et al., 2026). CBL engages students in investigating meaningful problems, identifying relevant questions, developing possible solutions, and evaluating their proposals through collaboration and evidence-based reasoning. A systematic review by Galdames-Calderón et al. (2024), which examined 64 publications on CBL in higher education, identified student-centered learning, technological integration, industry engagement, and developmental support as important dimensions of CBL implementation. The review also highlighted the need for further research into specific teaching practices and their contributions to student development. These findings suggest that CBL can provide a pedagogical foundation for connecting scientific knowledge with practical problem-solving, although its effectiveness depends on the learning design, instructional support, and outcomes being evaluated. In biotechnology education, this approach is particularly relevant because students must learn not only biological mechanisms but also how to assess scientific uncertainty, interpret experimental findings, and consider the ethical and practical implications of emerging technologies.

Breast-milk-derived bioactive peptides provide an innovative scientific context for implementing CBL in biomedical education. Human breast milk contains biologically active molecules that contribute to nutritional and physiological processes, offering opportunities to investigate the relationships between molecular structure, biological function, and potential therapeutic applications (Andreas et al., 2015). One notable example is HAMLET, a complex involving human alpha-lactalbumin and oleic acid that has been investigated for its tumor-cell-killing activity in experimental research. This research has contributed to scientific interest in the relationship between naturally occurring milk components and potential anticancer strategies. Building on related scientific work, Hamlet BioPharma has been developing Alpha1H, a synthetic peptide-based investigational candidate for non-muscle-invasive bladder cancer. In June 2026, the company announced an expansion of its clinical-development program in collaboration with the University of Iowa to investigate its potential application in patients with carcinoma in situ, a high-risk form of bladder cancer (Hamlet BioPharma, 2026). These developments provide an authentic example of how biological observations can stimulate further scientific investigation and therapeutic development. Nevertheless, the biological properties of breast milk, experimental findings involving bioactive complexes, and the clinical status of a particular drug candidate must be distinguished carefully. The educational value of this case lies in examining the scientific process and evaluating evidence, rather than assuming that breast milk itself constitutes a cancer treatment or that an investigational therapy has established clinical effectiveness.

Integrating this biomedical case into challenge-based learning could create opportunities for students to explore how scientific discoveries are translated into potential innovations (Rajendran et al., 2024). Rather than receiving information about molecular biology and cancer research solely through lectures, students could investigate a structured challenge concerning the scientific, ethical, and translational questions raised by breast-milk-derived bioactive peptides. Learning activities might include examining published research, distinguishing laboratory evidence from clinical evidence, developing conceptual explanations of biological mechanisms, evaluating the limitations of scientific claims, and proposing educational or research-informed responses to biomedical problems. Such activities could connect molecular biology with scientific literacy, critical thinking, evidence evaluation, and responsible innovation. Importantly, students would not need to conduct experiments involving cancer cells or develop therapeutic products to engage meaningfully with the scientific questions. Instead, they could work with published evidence, research scenarios, and structured problem-solving tasks that encourage them to understand how biomedical knowledge is generated, assessed, and translated into potential applications.

The educational rationale for this approach is also consistent with research on inquiry-based science education. A systematic review by (Muhamad Dah et al., 2024) examined the impacts of open inquiry on science learning, emphasizing the importance of investigating how learners engage in scientific questions and inquiry processes. Similarly, a systematic review of inquiry-based science education in teacher education identified opportunities for developing scientific understanding and investigative abilities, while noting challenges in transferring inquiry experiences into practice. Although inquiry-based learning and CBL are distinct approaches, both emphasize active engagement with problems and evidence rather than passive reception of information. CBL may extend these principles by situating scientific investigation within a broader challenge that requires students to integrate knowledge, collaborate, and formulate defensible responses. Accordingly, the proposed learning context could support the development of scientific reasoning and biotechnology literacy while introducing students to the interdisciplinary nature of biomedical innovation. However, these potential benefits should be treated as research questions rather than assumed outcomes.

Despite the growing literature on CBL in higher education and inquiry-based science education, further investigation is warranted into how emerging biomedical research cases can be designed as educational challenges and evaluated against clearly defined learning outcomes (Nizamis et al., 2026). In particular, the educational potential of breast-milk-derived bioactive peptides as a context for cancer research education requires empirical examination. The central issue is not simply whether students find the topic interesting, but whether engaging with the case through CBL helps them interpret scientific evidence, explain biological concepts, recognize uncertainty, and develop feasible and ethically informed responses to biomedical challenges. Addressing this issue requires a learning design that explicitly connects the scientific content, the challenge-solving process, and measurable educational outcomes. It also requires distinguishing students' perceptions of the learning experience from demonstrated changes in their knowledge and competencies.

Therefore, this study aims to investigate the use of Challenge-Based Learning incorporating breast-milk-derived bioactive peptides and cancer research as a context for developing future biomedical innovators. Specifically, the study examines students' biotechnology literacy, scientific reasoning, critical thinking, and biomedical innovation competencies following participation in the proposed learning approach. Where an appropriate comparison group is available, the study also compares these outcomes with those achieved through conventional instruction or an alternative learning approach. By connecting an emerging biomedical research context with an evidence-oriented pedagogical framework, this study seeks to contribute to biotechnology education research and provide insights into how authentic scientific challenges can be used to prepare students for interdisciplinary problem-solving and responsible biomedical innovation.

LITERATURE REVIEW

Challenge-Based Learning in Higher Education

Challenge-Based Learning (CBL) is a student-centered pedagogical approach that organizes learning around meaningful challenges requiring investigation, collaboration, and the development of evidence-informed solutions. Rather than focusing exclusively on the acquisition of disciplinary knowledge, CBL encourages students to apply what they learn to complex situations, formulate relevant questions, evaluate available information, and communicate possible responses. This approach is particularly relevant to higher education because professional practice increasingly requires graduates to integrate knowledge across disciplinary boundaries and respond to problems that do not have straightforward solutions.

(Galdames-Calderón et al., 2024) conducted a systematic review of CBL teaching practices in higher education and identified several important dimensions of implementation, including student-centered learning, technological integration, collaboration with external stakeholders, and appropriate instructional support. Their review highlights the importance of considering how challenges are designed and facilitated rather than assuming that the presence of a real-world problem automatically produces effective learning. CBL therefore requires alignment between the challenge, learning activities, expected competencies, and assessment procedures.

For biotechnology education, this pedagogical approach offers opportunities to connect theoretical concepts with authentic scientific problems. Students may investigate biological mechanisms, examine scientific publications, compare competing explanations, and develop research-informed proposals. Such activities can help students recognize that scientific knowledge is provisional, evidence-dependent, and subject to continued investigation. However, CBL should not be treated as inherently superior to conventional instruction. Its educational effectiveness must be established through appropriate learning assessments and, where feasible, comparisons with alternative instructional approaches.

In the present study, CBL is conceptualized as a structured learning process in which students investigate the scientific and educational challenges associated with breast-milk-derived bioactive compounds and cancer research. The approach emphasizes evidence evaluation, interdisciplinary integration, collaborative problem-solving, and the development of scientifically defensible proposals. This conceptualization provides the pedagogical foundation for examining whether an authentic biomedical research context can support the development of competencies associated with future biomedical innovation.

Breast-Milk-Derived Bioactive Compounds as an Authentic Learning Context

Human breast milk contains proteins, lipids, oligosaccharides, and other biologically active components that contribute to infant nutrition and physiological development. Its molecular complexity also provides an opportunity to examine the relationship between biological structure, molecular interactions, and biological function. Within biotechnology education, these characteristics make human milk a potentially valuable context for integrating biochemistry, molecular biology, physiology, and biomedical research.

An important example is HAMLET, an acronym for human alpha-lactalbumin made lethal to tumor cells. Research describes HAMLET-type complexes as protein–fatty acid complexes with biological activities that differ from those of their individual components (Fontana et al., 2013). The HAMLET complex consists of partially unfolded human alpha-lactalbumin associated with oleic acid. Experimental investigations have reported tumor-cell-killing activity and examined the molecular mechanisms underlying this activity.

These findings provide an instructive example of how changes in molecular conformation and interactions between biological molecules may influence biological function. Students can use this case to investigate protein structure, molecular interactions, experimental design, mechanisms of cell death, and the distinction between laboratory findings and clinical evidence. The case also encourages discussion of scientific uncertainty, reproducibility, and the limitations of extrapolating results from experimental models to human therapeutic applications.

An important conceptual distinction is necessary, however. HAMLET is a protein–lipid complex, not simply a peptide, and the presence of biologically active compounds in breast milk does not establish that breast milk itself is a cancer treatment. Moreover, the therapeutic development of synthetic peptide candidates inspired by this research should not be conflated with the composition or clinical effects of natural breast milk. Maintaining these distinctions is educationally valuable because it encourages students to evaluate scientific claims precisely and recognize the differences between natural biological materials, experimentally investigated molecular complexes, and investigational therapeutic candidates.

Accordingly, breast-milk-derived bioactive compounds can be positioned as an authentic learning context rather than as a predetermined therapeutic solution. Their educational value lies in the scientific questions they generate and the opportunities they provide for students to analyze molecular mechanisms, evaluate research evidence, and understand the process through which scientific observations may inform further biomedical investigation.

Translational Biomedical Research and Innovation Education

Translational biomedical research involves processes through which scientific discoveries are investigated for their potential relevance to disease understanding, diagnosis, prevention, or treatment. The pathway from basic research to clinical application is complex and typically requires multiple stages of investigation, validation, safety assessment, and regulatory evaluation. Understanding this pathway is important for students because promising experimental findings do not necessarily translate into effective or safe clinical interventions.

Research involving HAMLET illustrates several dimensions of this process. Initial investigations of the complex generated questions concerning its molecular structure, interactions with tumor cells, and potential biological selectivity. Subsequent studies investigated its mechanisms of action and possible therapeutic applications in experimental models and clinical settings (Shi et al., 2026). This body of research provides a context for exploring how scientific hypotheses are developed, how experimental evidence accumulates, and why further validation is necessary before therapeutic conclusions can be drawn.

In an educational setting, translational research can serve as a framework for examining the relationship between scientific discovery and responsible innovation. Students can investigate how researchers formulate hypotheses, determine suitable experimental approaches, interpret results, and identify limitations. They can also consider the ethical, regulatory, and societal dimensions of therapeutic development. These activities provide opportunities to connect foundational scientific knowledge with broader questions concerning the responsible use of biomedical discoveries.

Integrating translational research into CBL may encourage students to consider not only whether a scientific idea is biologically plausible but also what evidence would be required to evaluate it. For example, students could be challenged to construct an evidence map showing the progression from a molecular observation to experimental validation and potential clinical investigation. They could then identify unresolved questions and explain why different types of evidence are necessary at different stages of development.

This approach does not require students to conduct laboratory experiments involving cancer cells or to propose unvalidated treatments for patients. Instead, it emphasizes the intellectual processes through which biomedical research is interpreted and evaluated. The resulting learning experience may help students understand that biomedical innovation involves scientific rigor, interdisciplinary collaboration, ethical responsibility, and the recognition of uncertainty.

Scientific Reasoning, Biotechnology Literacy, and Biomedical Innovation Competencies

The development of future biomedical innovators requires more than factual knowledge of biological processes. Students must also be able to interpret evidence, distinguish observations from assumptions, evaluate competing explanations, and construct arguments supported by scientific information. These abilities are closely associated with scientific reasoning and biotechnology literacy.

Scientific reasoning involves the use of evidence and logical argument to formulate hypotheses, interpret findings, assess explanations, and recognize the limitations of available information. Inquiry-based science education provides a relevant theoretical foundation for these processes. (Muhamad Dah et al., 2024), in a systematic review of open inquiry in science education, examined outcomes related to conceptual understanding, motivation, attitudes toward science, scientific and thinking skills, and science literacy. Their findings also emphasized that the effectiveness of inquiry depends on appropriate implementation and support. Similarly, (Urdanivia Alarcon et al., 2023) reviewed inquiry-based teaching and learning in science and highlighted the importance of active scientific investigation in educational practice.

Although inquiry-based learning and CBL are not identical, both approaches emphasize engagement with questions, evidence, and problem-solving. CBL adds a broader challenge-oriented structure in which students integrate their findings into a proposed response or solution. In the context of biomedical education, this structure may help students connect scientific reasoning with the evaluation of potential innovations.

Biotechnology literacy refers here to students' ability to understand relevant biological and technological concepts, interpret biotechnology research, evaluate scientific claims, and recognize the implications and limitations of potential applications. In the proposed learning context, this includes understanding the distinction between a naturally occurring milk protein, a protein–lipid complex such as HAMLET, and a synthetic investigational therapeutic candidate. Such distinctions are important for developing scientifically accurate interpretations of biomedical research.

Biomedical innovation competency is conceptualized as the ability to use scientific knowledge and evidence to formulate feasible, ethically informed, and scientifically justified responses to biomedical challenges. It may include problem identification, interdisciplinary knowledge integration, evidence-based proposal development, ethical awareness, and scientific communication. These competencies are relevant to the present study because the goal is not to train students to develop a cancer therapy independently, but to help them understand and engage responsibly with the processes through which biomedical innovations are investigated.

For empirical evaluation, these constructs should be operationalized separately. Biotechnology literacy can be assessed through concept-based questions and the interpretation of scientific information. Scientific reasoning can be evaluated through tasks requiring hypothesis formulation, evidence assessment, and the identification of uncertainty. Biomedical innovation competency can be assessed through a rubric examining the scientific rationale, feasibility, ethical considerations, and evidence supporting students' proposed responses. Clear operational definitions will help distinguish demonstrated learning outcomes from students' subjective perceptions of the learning experience.

Integrating Challenge-Based Learning with Breast-Milk-Derived Peptide Research

The preceding literature suggests a conceptual connection between CBL, authentic biomedical research, and the development of scientific competencies (Lim & Veasuvalingam, 2025). CBL provides the pedagogical structure for investigating meaningful challenges, while breast-milk-derived bioactive compounds and cancer research provide a scientifically rich context for interdisciplinary investigation. Scientific reasoning, biotechnology literacy, and biomedical innovation competencies represent potential outcomes through which the educational contribution of this integration can be examined.

A learning sequence based on this integration could begin with a challenge concerning how a biological discovery can be evaluated for its potential relevance to cancer research. Students would then investigate the molecular background, examine published evidence, distinguish experimental findings from clinical conclusions, and identify unresolved scientific questions. Working collaboratively, they could develop an evidence-based research interpretation or educational proposal and present their reasoning for critical evaluation by peers and instructors.

The instructional design should include appropriate scaffolding, particularly because the scientific content involves molecular mechanisms and the interpretation of biomedical evidence. Students may require guidance in evaluating publication quality, distinguishing different levels of evidence, and avoiding unsupported conclusions about therapeutic efficacy. Assessment should therefore consider not only the final proposal but also the quality of students' reasoning, the accuracy of their scientific interpretations, and their ability to justify decisions with evidence.

This integration also creates an opportunity to examine whether authentic biomedical cases contribute educational value beyond general problem-based activities. The specific scientific context may increase the relevance of biotechnology concepts and provide a concrete example of the relationship between fundamental research and potential clinical applications. Nevertheless, the contribution of the context cannot be inferred from its scientific novelty alone. It must be evaluated through student performance and appropriately designed research procedures.

Research Gap and Conceptual Framework

Existing literature provides foundations for the separate components of the proposed study. Research on CBL examines its instructional practices and application in higher education (Saifi et al., 2024). Research on HAMLET and related bioactive complexes provides a scientific basis for understanding the molecular and experimental dimensions of breast-milk-derived bioactive research (Szyller et al., 2024). Meanwhile, systematic reviews of inquiry-based science education examine learning processes and outcomes related to scientific understanding, reasoning, and science literacy (Muhamad Dah et al., 2024).

However, the educational contribution of combining these components requires further investigation. In particular, it remains necessary to determine whether using breast-milk-derived bioactive peptides and cancer research as the context for CBL can support measurable improvements in biotechnology literacy, scientific reasoning, and biomedical innovation competency. The proposed study therefore addresses a focused pedagogical question: whether students' engagement with an authentic biomedical research challenge can support the development of competencies needed to interpret scientific evidence and formulate responsible innovation proposals.

The conceptual framework proposes that participation in structured CBL activities may influence these three learning outcomes through active investigation, evidence evaluation, collaborative problem-solving, and scientific communication. The framework treats the learning approach as the instructional component and the three competencies as distinct outcome variables. Where a comparison group and pre-intervention measurements are included, the study can examine whether changes in these outcomes are associated with participation in CBL rather than relying solely on students' perceptions.

The framework also recognizes that learning outcomes may depend on prior scientific knowledge, instructional support, the duration of the intervention, and the quality of the learning materials. These factors should be considered when designing the intervention and interpreting its results. By evaluating the proposed integration empirically, the study seeks to contribute to biotechnology education research and clarify how authentic biomedical research can be used to develop scientific reasoning and innovation-oriented learning.

METHODOLOGY

Research Design

This study employs a qualitative descriptive research design to explore the potential of Challenge-Based Learning (CBL) in developing biomedical innovation competencies through breast-milk-derived bioactive peptides and cancer research education. The study focuses on students' learning experiences, understanding of scientific evidence, critical thinking, and perceptions of biomedical innovation (Anggraeni et al., 2023). A qualitative approach is appropriate because the research seeks to understand how students interpret and engage with an authentic biomedical challenge rather than measure statistical differences in learning outcomes.

Participants

The participants will consist of students enrolled in biotechnology, biology, biomedical science, or related higher education programs. Participants will be selected using purposive sampling based on their relevance to the learning activities and willingness to participate. The number of participants will depend on the study context and the depth of qualitative data obtained.

Learning Activities and Data Collection

The study will implement a CBL activity centered on breast-milk-derived bioactive compounds and their investigation in cancer research. Students will examine selected scientific publications, discuss the distinction between experimental findings and clinical evidence, identify relevant scientific questions, and develop evidence-based proposals addressing the biomedical challenge.

Data will be collected through students' written reflections, group discussions, and proposed solutions. These materials will provide insights into how students interpret scientific information, evaluate evidence,

collaborate in problem-solving, and understand the relationship between basic research and potential biomedical applications.

Data Analysis

The qualitative data will be analyzed using thematic analysis. The analysis will involve familiarization with the data, initial coding, grouping related codes, developing themes, and interpreting the findings in relation to the research objectives. The analysis will focus on three themes: (1) biotechnology literacy and understanding of scientific evidence, (2) scientific reasoning and critical thinking, and (3) biomedical innovation and responsible problem-solving.

Trustworthiness and Ethical Considerations

Trustworthiness will be supported through triangulation of students' reflections, group discussions, and written proposals. Clear documentation of the coding and theme-development process will help maintain transparency. Participation will be voluntary, and informed consent will be obtained before data collection. Student identities will be protected through anonymization, and the data will be used only for the stated research purposes. The study will focus on published scientific evidence and educational activities, without conducting experiments on cancer cells or making claims about the clinical effectiveness of investigational therapies.

RESULTS AND DISCUSSION

Overview of the Findings

The qualitative analysis was designed to explore how Challenge-Based Learning (CBL), using breast-milk-derived bioactive peptides and cancer research as an educational context, could support students' understanding of biotechnology, scientific reasoning, and biomedical innovation. The analysis framework focused on three themes: biotechnology literacy and scientific evidence, scientific reasoning and critical thinking, and biomedical innovation and responsible problem-solving.

The findings should be interpreted through students' written reflections, group discussions, and proposed solutions (Zhang, 2023). These sources provide complementary perspectives on how students understand the scientific case, engage with evidence, and formulate responses to the challenge. The following sections present the three analytical themes as a structure for reporting the findings.

Biotechnology Literacy and Understanding of Scientific Evidence

The first theme concerns students' understanding of breast-milk-derived bioactive compounds and their relevance to cancer research. The learning challenge provides an opportunity to examine how students connect concepts from molecular biology and biochemistry with contemporary biomedical research. Through the analysis of scientific publications, students are expected to distinguish naturally occurring biological components from experimentally investigated molecular complexes and investigational therapeutic candidates.

An important aspect of this theme is the distinction between experimental evidence and clinical evidence. Research involving HAMLET, a complex formed from human alpha-lactalbumin and oleic acid, provides a case for examining how molecular observations can generate hypotheses about potential biomedical applications. Students can investigate the scientific rationale behind such research while recognizing that findings from experimental studies do not automatically establish therapeutic effectiveness in humans.

Students' written reflections and discussions should be examined for evidence of conceptual understanding, accurate interpretation of scientific claims, and recognition of research limitations. Particular attention should be given to whether students can explain the differences between biological plausibility, experimental findings, and demonstrated clinical outcomes.

This theme is relevant to biotechnology education because scientific literacy involves more than remembering biological facts. It also requires the ability to evaluate information, interpret research findings, and recognize uncertainty. The CBL approach provides a structured opportunity for students to engage with these processes through an authentic biomedical case.

Scientific Reasoning and Critical Thinking

The second theme concerns how students formulate scientific questions, evaluate evidence, and develop reasoned explanations. The challenge-based activity requires students to examine published research, identify relevant scientific problems, discuss alternative interpretations, and justify their conclusions.

Group discussions can provide insights into how students evaluate the reliability of scientific claims and respond to uncertainty. Their written proposals can further demonstrate whether arguments are supported by relevant evidence and whether limitations are acknowledged. For example, students may be asked to identify what additional evidence would be necessary to assess a proposed therapeutic application and explain why laboratory findings alone are insufficient to establish clinical effectiveness.

From a pedagogical perspective, these activities connect CBL with inquiry-oriented learning. Galdames-Calderón et al. (2024) emphasized the importance of instructional design and implementation in CBL, while research on inquiry-based science education highlights the role of investigation and evidence-based reasoning in science learning (Dah et al., 2024).

The qualitative analysis should therefore examine how students construct arguments, integrate information from different sources, respond to alternative explanations, and justify their proposed conclusions. It should also identify difficulties, such as unsupported assumptions, confusion between correlation and causation, or an inability to distinguish promising scientific hypotheses from established conclusions.

These findings would help clarify how students engage with scientific uncertainty and whether the learning activities provide meaningful opportunities to practice critical thinking. However, claims that CBL improves critical thinking should be made only when supported by the actual qualitative evidence and appropriate interpretation.

Biomedical Innovation and Responsible Problem-Solving

The third theme focuses on students' ability to formulate scientifically justified and ethically informed responses to a biomedical challenge. In the proposed learning activity, students are expected to move beyond summarizing scientific publications and develop proposals that demonstrate an understanding of the research problem, the available evidence, and the limitations of potential applications.

Students' written proposals can be analyzed according to four dimensions: clarity of the problem definition, relevance of the supporting scientific evidence, feasibility of the proposed response, and consideration of ethical and clinical limitations. Group discussions may provide additional information about how students negotiate different ideas, integrate disciplinary perspectives, and justify their decisions.

The educational value of this process lies in helping students understand that biomedical innovation involves more than generating novel ideas. Responsible innovation also requires scientific validation, consideration of potential risks, appropriate ethical standards, and recognition of the boundaries of current knowledge.

In the context of breast-milk-derived bioactive compounds, students should be encouraged to develop research-informed educational or scientific proposals rather than make unsupported claims about cancer treatment. Such an approach positions biomedical innovation as a process of evidence-based inquiry and responsible decision-making.

The analysis should identify whether students demonstrate these characteristics in their proposals and discussions. It should also document barriers encountered during the activity, including difficulties interpreting technical literature, limited prior knowledge, or challenges in integrating scientific and ethical considerations.

Integrating the Three Themes Through Challenge-Based Learning

The three themes are conceptually interconnected. Biotechnology literacy provides the scientific foundation for interpreting the research case, scientific reasoning enables students to evaluate evidence and construct defensible arguments, and biomedical innovation involves applying this understanding to develop responsible proposals.

CBL offers a pedagogical structure through which these dimensions can be addressed in an integrated learning experience. Rather than studying molecular biology, research methodology, and innovation as isolated subjects, students engage with a common challenge that requires them to connect these areas.

Nevertheless, the relationship among the three themes should be established through the qualitative data rather than assumed in advance. For example, the analysis may reveal that students who demonstrate accurate scientific interpretation also produce more carefully justified proposals. Alternatively, students may understand the biological concepts but struggle to translate their knowledge into feasible solutions. Such differences would provide useful insights into the strengths and limitations of the learning design.

The analysis should therefore consider both the ways in which the themes reinforce one another and the difficulties students encounter when moving from scientific understanding to evidence-based problem-solving.

Implications for Biotechnology Education

The proposed findings have implications for the design of biotechnology education in higher education. Authentic biomedical cases can provide meaningful contexts for connecting fundamental scientific concepts with current research questions. When combined with structured investigation, collaborative discussion, and evidence-based proposal development, these cases may create opportunities for students to engage more deeply with the processes of scientific inquiry.

The use of breast-milk-derived bioactive peptides and cancer research also illustrates the importance of integrating scientific literacy with ethical awareness. Students must learn not only how to interpret emerging biomedical research but also how to communicate its implications accurately and distinguish potential applications from established treatments.

For educators, this approach suggests the value of designing challenges that are scientifically authentic but appropriately scoped for students' knowledge and learning objectives. Carefully selected publications, guided questions, structured discussion, and transparent assessment criteria can help students engage with complex research without requiring advanced laboratory facilities.

However, the qualitative design limits the conclusions that can be drawn about the effectiveness of CBL. Students' reflections and proposals can reveal how they understand and experience the learning process, but they do not independently establish causal improvements in competencies. The findings should therefore be interpreted as context-specific insights into students' learning experiences and demonstrated reasoning rather than definitive evidence of superior learning outcomes.

Summary of the Discussion

This study provides a framework for examining the educational potential of integrating CBL with breast-milk-derived bioactive peptide research and cancer science. The three analytical themes—biotechnology literacy, scientific reasoning, and biomedical innovation—offer a coherent structure for investigating students' engagement with authentic biomedical challenges.

The principal contribution of the study will depend on the evidence obtained from students' reflections, group discussions, and written proposals. If the data demonstrate meaningful engagement with scientific evidence, recognition of uncertainty, and the development of reasoned proposals, the study may offer useful insights into how authentic biomedical research can inform innovative biotechnology education.

Ultimately, the educational objective is not to present breast-milk-derived compounds as established cancer treatments, but to use an emerging field of biomedical research to help students understand how scientific discoveries are evaluated, challenged, and responsibly translated into potential applications.

CONCLUSION

Conclusion

This study presents Challenge-Based Learning (CBL) as a potential pedagogical approach for integrating breast-milk-derived bioactive peptide research and cancer science into biotechnology education. By engaging students with an authentic biomedical challenge, the proposed learning framework connects scientific knowledge with evidence evaluation, critical thinking, and responsible innovation. The study focuses on three key dimensions: biotechnology literacy, scientific reasoning, and biomedical innovation competencies. Its contribution lies in providing an educational framework through which students can explore the process of translating scientific discoveries into potential biomedical applications. The conclusions regarding its educational value should ultimately be grounded in the qualitative evidence collected from students' reflections, group discussions, and written proposals.

Implications

The proposed approach has implications for biotechnology, biology, and biomedical science education. First, educators can use emerging biomedical research to connect theoretical concepts with authentic scientific problems. Second, CBL can provide opportunities for students to examine scientific evidence, recognize uncertainty, and develop reasoned responses to complex challenges. Third, incorporating ethical considerations into biomedical case studies can strengthen students' understanding of responsible scientific communication and innovation. This approach can be implemented through literature analysis, collaborative discussions, and research-based proposals without requiring specialized laboratory facilities or direct experimentation involving cancer cells.

Limitations

This study has several limitations. The qualitative research design provides contextual insights into students' experiences and reasoning but does not establish causal relationships between CBL and learning outcomes. The findings may also depend on participants' prior scientific knowledge, the instructional context, and the quality of the learning materials. Furthermore, the biomedical case involves specialized concepts that may be challenging for students without sufficient background knowledge. The use of published research as the primary scientific resource also means that the learning experience depends on students' ability to interpret existing evidence rather than generate new experimental findings. Finally, the educational framework should not be interpreted as evidence of the clinical effectiveness of breast-milk-derived compounds or investigational cancer therapies.

Recommendations

Educators are encouraged to integrate authentic biomedical research cases into CBL activities supported by structured learning materials and guided scientific inquiry. Students should be encouraged to distinguish experimental evidence from clinical evidence, evaluate the limitations of scientific claims, and develop proposals that reflect scientific accuracy and ethical responsibility. Instructors should provide clear assessment criteria for biotechnology literacy, scientific reasoning, and biomedical innovation competencies. The learning activities should also be adapted to students' academic backgrounds and levels of scientific understanding to ensure accessibility and meaningful engagement.

Future Research

Future research should examine the implementation of this learning framework across different educational settings, including biotechnology, biology, biomedical science, and interdisciplinary STEM programs. Further qualitative studies could investigate how students develop their understanding of scientific uncertainty, evidence evaluation, and responsible biomedical innovation over time. Research could also explore how digital learning resources, AI-assisted literature analysis, and collaborative learning environments support engagement with complex biomedical topics. Subsequent studies may employ mixed-methods or comparative designs to examine changes in specific learning outcomes and compare CBL with alternative pedagogical approaches. Additional investigations should establish the validity and reliability of assessment instruments for biomedical innovation competencies and determine which instructional components contribute most meaningfully to students' learning.

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APPENDIX

