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SciEd

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Director's Message

Dear Esteemed Readers,
We are honoured to present Volume 5, Issue 1 of the SEAQIS Journal of Science Education (SciEd). This milestone reflects our unwavering commitment to advancing science education across Southeast Asia.

In this edition, we delve into innovative pedagogical approaches, cutting-edge research, and transformative practices that are shaping the future of science education. The articles featured herein offer valuable insights into STEM integration, utilization of technology to enhance learning outcomes and the role of science education in national economic development. These contributions not only enrich our understanding but also inspire educators to implement effective strategies in their classrooms.

As we navigate the evolving landscape of education, the role of science educators becomes increasingly pivotal. It is through their dedication and ingenuity that we can foster scientific literacy and critical thinking skills among learners. We extend our heartfelt appreciation to the authors, reviewers, and editorial team whose efforts have culminated in this publication.

We invite you to engage with the research presented in this issue and consider its implications for your practice. Together, let us continue to collaborate, innovate, and elevate the standards of science education in our region.

Sincerely,

Reza Setiawan, S.Si., M.T.
Director, SEAMEO QITEP in Science

From the Editor-in-Chief

It is with great pleasure that I welcome you to Volume 5, Issue 1 of the SEAQIS Journal of Science Education (SciEd).

This issue continues our commitment to presenting scholarly work that advances the field of science education, with a focus on both regional and global perspectives. The articles in this edition explore a wide range of topics, from innovative teaching practices to role of Science Education in National Economic, demonstrating the breadth and depth of research that drives progress in science education today.

I would like to extend my sincere appreciation to all contributors, including the authors, reviewers, editorial board members, designers, and the publishing office staff. Their professionalism and dedication have been instrumental in ensuring the quality and integrity of this publication.

At SciEd, we believe in the importance of fostering a space for critical inquiry, collaboration, and academic dialogue. This journal serves not only as a platform for sharing research but also as a forum for exchanging ideas that can shape the future of science education. We encourage our readers to engage with the content, reflect on the insights provided, and consider the implications for their own contexts and practices.

Thank you for your continued support of SciEd. We hope that the articles presented in this issue will contribute meaningfully to your work and inspire further inquiry into the evolving landscape of science education.

Warm Regards,

Dr. Elly Herliani, M.Phil., M.Si.

Table of Contents

SEAQIS Journal of Science Education (SciEd)

Volume 5 | No 1 | June 2025
E-ISSN 2964-7533 | P-ISSN 2987-8101

The Desk

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Research Paper Open Accsess

A Comprehensive Analysis using RStudio: Augmented Reality in Microbiology Mapping

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Abstract

Augmented Reality (AR) is an emerging technology with significant potential across various domains, including microbiology. However, despite increasing interest, the research landscape at the intersection of AR and microbiology remains underexplored. This study conducts a bibliometric analysis to map the current state of research on AR in microbiology, identifying key trends, contributors, and thematic developments. Using RStudio and the bibliometric R-package, the researchers analysed publications indexed in the Scopus database from the past five years, employing performance analysis (e.g., publication growth, country productivity, and leading sources) and science mapping techniques such as co-word analysis and thematic mapping. The study focused on the keywords "augmented reality" and "microbiology" to identify relevant literature, resulting in 10 documents. The findings reveal a gradual increase in publications, especially in recent years, with the United States emerging as the leading contributor. Keyword co-occurrence analysis identified "augmented reality", "microbiology", and "human" as central themes. The thematic analysis highlighted key areas such as the design and evaluation of AR tools for microbiology education, their effects on student learning outcomes, and the challenges of integrating AR into instructional practices. These insights offer a foundation for advancing research and practical applications of AR in microbiology education. Future studies should continue to explore how AR can enhance learning experiences and outcomes in this field.

Keywords: AR; Artificial Intelligence; Microbiology; Microbiology Literacy; RStudio

Introduction

Augmented reality (AR) has emerged as a promising technology in various fields, including education (Alnajdi, 2022; Pathania et al., 2021; YAPICI & KARAKOYUN, 2021), with the potential to enhance learning experiences (Faith Marcel, 2019; Jung et al., 2021) through the visualisation of abstract concepts (Buchner et al., 2021; Nuanmeesri, 2018; Uriarte-Portillo et al., 2022). In the context of microbiology literacy, AR enables students to better understand microorganisms and their crucial roles in health and disease (Ingrassia et al., 2020). Research on the application of AR in microbiology education has grown rapidly in recent years, as evidenced by the increasing number of scientific publications in this field.

Microbiology literacy is not a newly developed concept; rather, it has re-emerged as a focal point, coinciding with the recent surge in publications within this field (Fidiastuti et al., 2025; Rachman et al., 2024; Timmis, 2023; Timmis et al., 2019, 2020). The microbiological context is not only related to the role of microorganisms alone, but also the green economy (Lorek & Spangenberg, 2014; Luo & Cheng, 2022; Vandegrift et al., 2017), sustainability (Obaideen et al., 2022; Tom et al., 2021), bioremediation and biodegradation (Fidiastuti et al., 2020b, 2020a; Rozana et al., 2023) as well as other essential roles.

Recent trends in AR-related publications in the Scopus database show significant growth (Buchner et al., 2021; Pathania et al., 2021). However, most prior studies have been small-scale and conducted in controlled settings, limiting understanding of AR's broader educational potential. Additionally, comprehensive bibliometric reviews on AR research in microbiology literacy are lacking, leaving gaps in knowledge about its long-term impact and application in diverse educational contexts.

This study addresses these gaps by conducting a bibliometric analysis of AR-related publications in microbiology literacy from 2020 to 2024. The analysis examines publication trends, research collaborations, and key themes in the literature. The findings aim to provide valuable insights for researchers, educators, and policymakers while identifying unexplored research opportunities to enhance AR's application in microbiology education.

Methodology

Research design

This study employs a quantitative bibliometric approach to systematically examine the research landscape at the intersection of augmented reality and microbiology. Bibliometric analysis enables the identification of trends, influential contributors, research dynamics, and thematic developments of trends, influential contributors, research dynamics, and thematic developments in this emerging interdisciplinary domain. The analysis was conducted using the bibliometric R-package in RStudio, which supports a range of performance and science mapping techniques, including publication growth analysis, co-authorship networks, keyword co-occurrence mapping, and thematic evolution.

Data Source

The data were sourced from the Scopus database, selected for its extensive coverage of peer-reviewed literature and consistent indexing standards. Scopus provides high-quality bibliographic data, including citation and authorship metadata, which is crucial for bibliometric assessment. All retrieved records were exported in BibTeX format to ensure compatibility with the analysis tools.

Inclusion and Exclusion Criteria

To ensure relevance and quality, the following inclusion criteria were applied:

a. Peer-reviewed publications from 2020 to 2024
b. documents containing the keywords "augmented reality" and "microbiology" or related terms in the title, abstract, or keywords
c. Publications with full-text availability for contextual validation
d. Articles are written in English to ensure consistency in keyword interpretation and analysis.
e. Documents such as conference summaries, editorial notes, and non-scholarly commentaries were excluded to maintain the focus on research-based literature.

Data Collection

The data collection process involved a structured search within Scopus using controlled keyword combinations. After the initial retrieval, duplicate entries and non-relevant documents were manually screened.

A final dataset of 10 relevant publications was selected for in-depth analysis. Extracted bibliographic metadata included titles, authorship, affiliations, publication sources, years, abstracts, and author keywords. An extended review of abstracts and available full texts was conducted to validate the contextual relevance of each article.

Data Analysis

The collected data were analysed using the bibliometric software package in the RStudio environment. Bibliometric analysis involves various techniques, including:

a. Descriptive analysis

   Calculating the number of publications, annual growth rate, average document age, average citations per document, and the number of references

b. Context analysis

   Identifying frequently occurring keywords, including those provided by authors and those generated automatically

c. Author analysis

   Identifying prolific and influential authors, as well as collaboration patterns among them

d. Document type analysis

   Classifying documents based on their type, such as articles, conference papers, reviews, and notes. However, due to the limited number of documents found, further categorisation was not performed, as only articles and conference papers were identified.

Additionally, keyword co-occurrence analysis and co-citation analysis were conducted to identify relationships between key concepts and influential authors in the field.

Results and Discussion

Annual Science Production

Figure 1 shows a decline in publications on AR and microbiology from 2020 to 2024. After a peak of 6 publications in 2020, there were none in 2021, 2 in 2022, and only 1 each in 2023 and 2024, indicating a reduced interest in this research area. However, this five-year period may not fully capture long-term trends, and further study is needed to explore the factors driving these publication patterns.

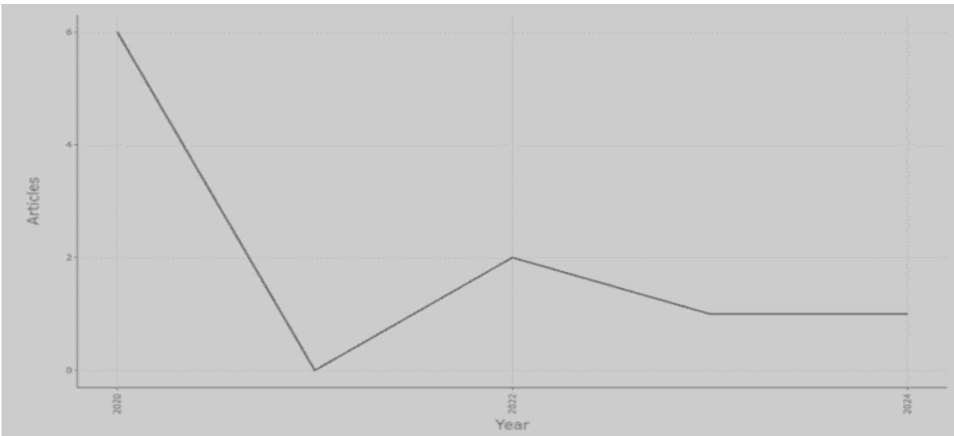

Figure 1. Annual Science Production (Source: RStudio)

Average Citations Per Year

Figure 2 shows a decline in the annual citations of research articles on AR and microbiology from 2020 to 2023, with a peak in 2020 followed by a sharp drop, reaching its lowest point in 2023. Several factors may explain this trend:

1. Declining Research Interest: Interest in AR and microbiology may have diminished due to shifts in focus, limited

funding, or the effects of the COVID-19 pandemic

2. Topic Saturation: Research in this intersection may have reached a saturation point, with key questions already extensively explored

3. Evolving Trends: Shifts in focus within AR and microbiology, such as moving from microbial identification to disease diagnosis, could have led to fewer citations for older topics.

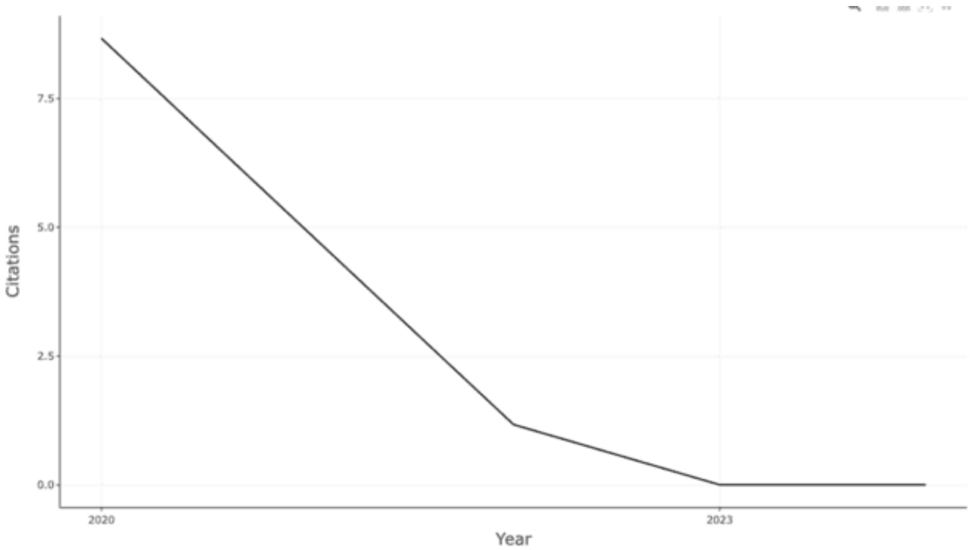

Figure 2. Average Citations Per Year (Source: RStudio)

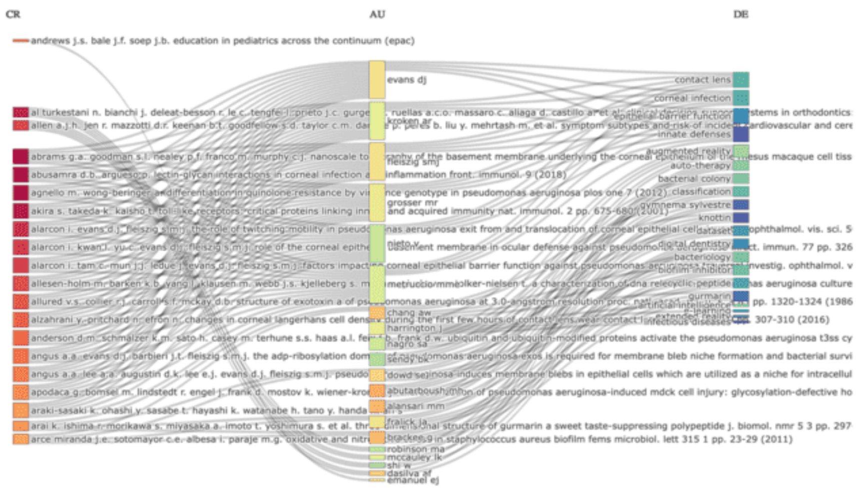

Figure 3. Three-Field Plot (Source: RStudio)

Three-Field Plot

Based on the bibliometric analysis in Figure 3, a notable correlation exists between AR and microbiology, particularly in research on corneal infections and epithelial defence. Fleiszig et al.'s work demonstrates the potential of AR in studying infections caused by Pseudomonas aeruginosa, focusing on bacterial motility, biofilm formation, and interactions with corneal epithelial cells (Fleiszig et al., 2020). Though the combination of AR and microbiology remains underexplored, the analysis suggests promising opportunities for future research. AR could play a pivotal role in advancing the understanding of infection mechanisms, developing innovative therapies, and enhancing microbiology education and training.

Most Relevant Sources

Figure 4 presents a bibliometric analysis of publications at the intersection of AR and microbiology, sourced from a range of reputable journals. The analysis revealed a small but expanding body of literature on AR's integration into microbiology. The Journal of Physics: Conference Series emerged as the most prolific source, with four publications, indicating a strong focus on AR research in microbiology, especially in conferences related to instrumentation or microorganism visualisation.

Other key journals included the 3rd International Conference on Computing, Frontiers in Cellular and Infection Microbiology, Journal of American Medical Association, JDR Clinical and Translational Research, Medical Science Educator, and Progress in Retinal and Eye Research. These publications demonstrate the diverse applications of AR in fields such as basic research, clinical practice, education, and ophthalmology. Overall, while the intersection of AR and microbiology remains underexplored, the growing interest across various disciplines suggests significant potential for future research to advance AR's role further in microbiology.

Authors' Production Over Time

The visualisation in Figure 5 reveals a gap in document publication in 2021, with a clustering of publications in 2020 and 2022. Authors Abutarboush MH and Alansari MM are notably represented with two publications each in 2022, contrasting with the single publication from each of the following authors: Brackee G.; Chang AW.; DaSilva AF.; Dowd SE.; Emanuel EJ.; Evans DJ.; Fleiszig SMJ.; and Fralick JA within the analysed period.

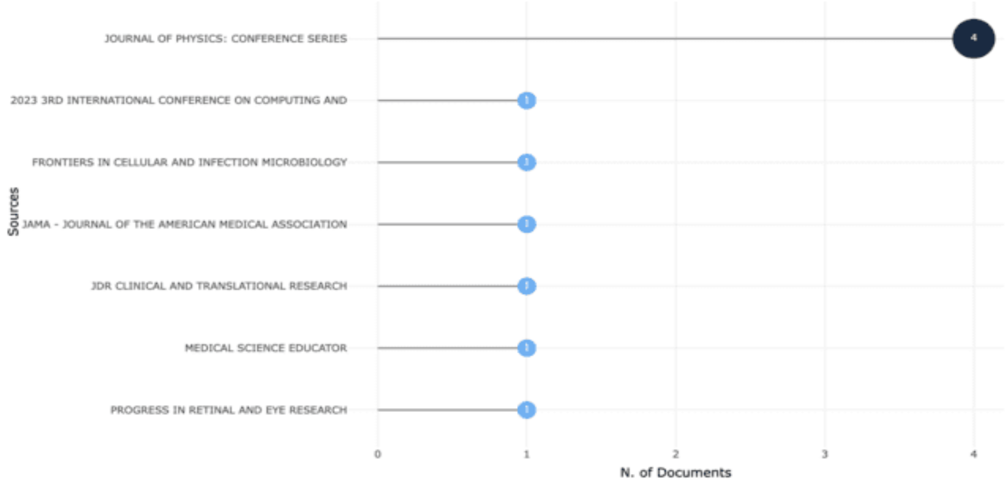

Figure 4. Most Relevant Sources (Source: RStudio)

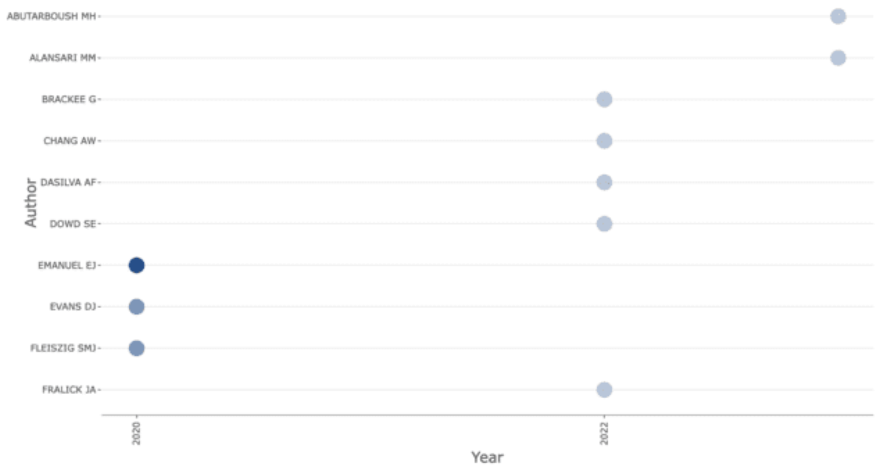

Figure 5. Authors Production Over Time (Source: RStudio)

Most Relevant Affiliations

The primary goal of this analysis is to identify the leading institutions contributing to AR research in microbiology, as indicated by citation frequency. Figure 6 highlights the institutional landscape in this field. The University of California stands out as the top contributor, with seven publications. Other notable institutions, each producing two publications, include the Institute of Wellness and Preventive Medicine, Kansas State University, Saudi Electronic University, Texas Tech University Health Science Center, and the University of Michigan School of Dentistry. Additionally, institutions such as Molecular Research DNA, Rocky Vista University, The Forsyth Institute, and The University of Alabama at Birmingham School of Dentistry contributed one cited document each. This overview provides insight into the distribution of research contributions across various academic and research institutions.

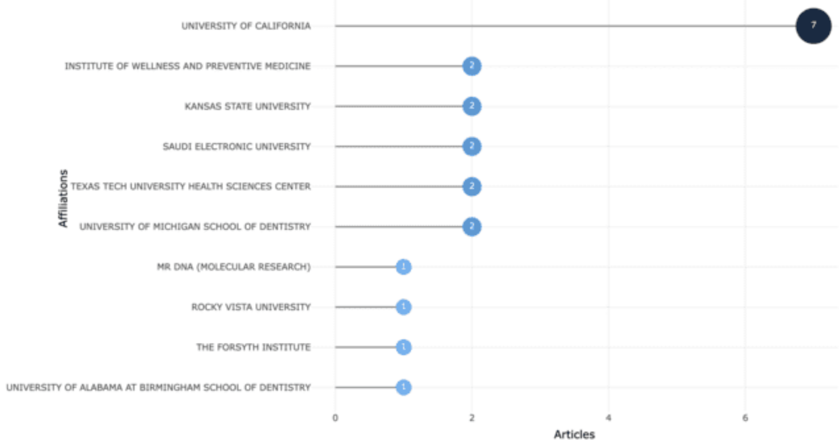

Figure 6. Most Relevant Affiliations (Source: RStudio)

Most Cited Countries

The citation analysis in Figure 7 reveals a notable disparity between the United States and Saudi Arabia in AR microbiology research. The United States received 267 citations, indicating a significant global impact, while Saudi Arabia received none. This suggests that U.S. research in this field has had a more substantial influence. However, it is important to recognise that this analysis is based on only 10 identified documents, and a broader analysis, including data from other databases, might uncover further contributions from Saudi Arabia.

Most Global Cited Documents

The document authored by Emanuel demonstrated the highest global citation impact, with 184 citations (Figure 8). This high citation count reflects the considerable influence of Emanuel's work and its standing as a key reference in the field. The limited body of literature on this topic likely contributes to the disproportionately high citation rate for this study.

Reference Spectroscopy

A significant rise in citations from publications spanning 1980 to 2022 suggests that earlier research likely laid the theoretical foundations for the development of AR in microbiology. The peak in citations occurred in 2022, establishing it as a landmark year for AR research in this field. As shown in Figure 9, the number of references published has followed a steady upward trend, reflecting the growing body of work.

However, there is a notable disparity between the number of published references and the annual citations received, indicating that AR research in microbiology heavily relies on earlier studies, which boosts its citation potential. Despite this, the quality of publications remains a key factor influencing how frequently they are cited.

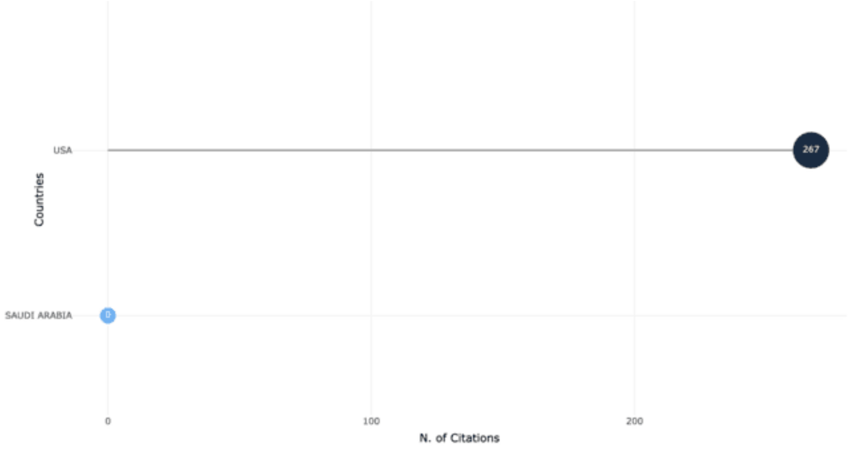

Figure 7. Most Cited Countries

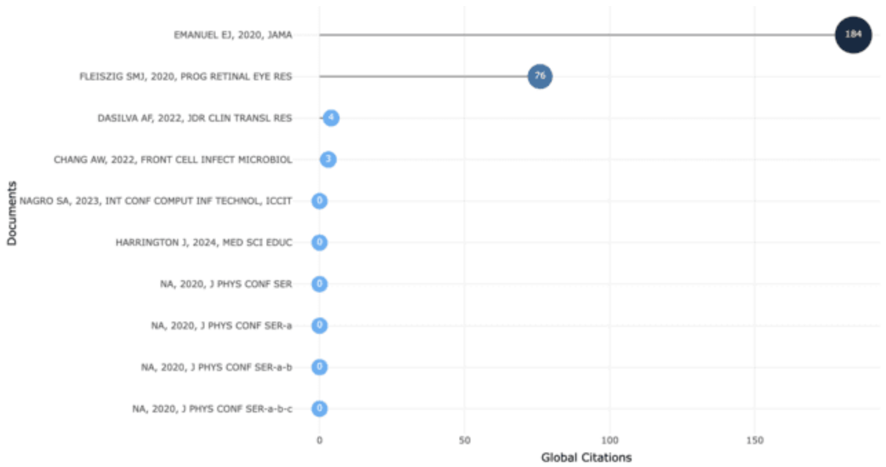

Figure 8. Most Global Cited Documents (Source: RStudio)

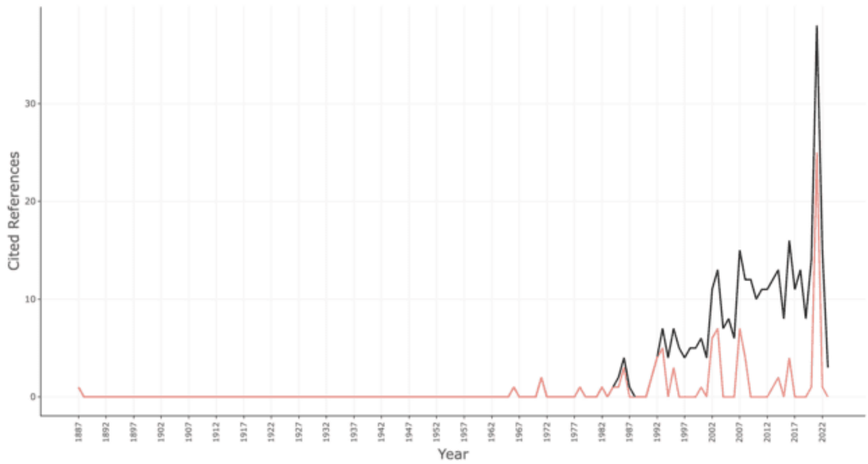

Figure 9. Reference Spectroscopy (Source: RStudio)

Most Frequent Words

Figure 10 underscores the central role of human-related concepts in AR research within microbiology. The keywords "augmented reality" and "human" appeared most frequently, each cited four times. This highlights the primary focus on human-centred applications of AR in this field. The keyword analysis offers a detailed perspective on the specific areas where AR technologies are being applied, particularly in developmental and practical applications within microbiology.

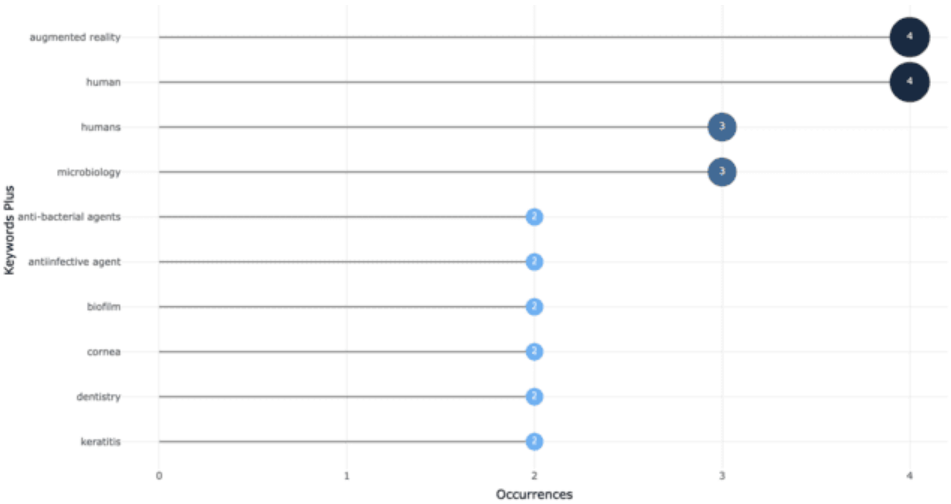

Figure 10. Most Frequent Words

Word Cloud

The word cloud visualisation (Figure 11) offers a comprehensive overview of the research landscape within the domain of AR in microbiology. Key findings from the analysis include:

1. Primary Focus

   The predominant terms within the word cloud are "augmented reality", "microbiology", and "human", indicating a concentrated focus on human-centric applications of AR technologies within the field of microbiology.

2. Medical Applications

   The appearance of keywords such as "antibacterial agents", "antibiotic resistance", "sepsis", "keratitis", "cornea", "dentistry", and "medical education" suggests a significant interest in utilising AR for medical applications, particularly in diagnosis, treatment, and education related to microbiology.

3. Bacterial Focus

   The frequent occurrence of terms like “bacterial microbiome”, “bacterial virulence”, “bacterial classifications”, “bacterium isolate”, “bacterial eye infection”, “bacterial colonies”, and “Staphylococcus aureus” demonstrates a substantial focus on bacteria and their interactions with humans within the context of AR research.

4. AI as A Supporting Technology

   The presence of the term “artificial intelligence” indicates the pivotal role of artificial intelligence in the development and application of AR technologies within microbiology.

5. Broader Implications

   The appearance of terms such as “cultural competence”, “collaborative learning”, “communication”, “skill”, “classification of information”, and “commercial phenomena” suggests a broader scope of research, encompassing social, economic, and educational dimensions.

Figure 11. Word Cloud (Source: RStudio)

The data analysed was sourced from the Scopus database, encompassing publications from seven different sources between 2020 and 2024. A total of 10 publications were included in this study. The annual growth rate analysis revealed a 36.11% decrease in the number of annual publications during the analysed period. The average document age was 2.9 years, indicating that most of the research was recent and relevant to current developments. Each document was cited an average of 26.7 times, suggesting a significant impact and recognition within the scientific community. All publications collectively referenced 337 documents demonstrating a strong theoretical foundation in augmented reality research related to microbiology.

A total of 131 keywords were identified from all analysed documents, indicating specific research topics. Authors employed an average of 39 unique keywords per document, reflecting the diversity of research field in this field. Twenty-two authors contributed to the analysed documents, with only two publishing individually. Each document had an average of 2.2 co-authors, suggesting a prevalent collaborative research culture in AR and microbiology. However, no international collaborations were identified, indicating a localised research scale. This presents an opportunity for future development.

The document types included articles, conference papers, conference reviews, short notes, literature reviews, and evaluations. Bibliometric analysis indicated a growing research field with significant author collaboration and a substantial research impact. Despite the decrease in the number of publications, research in this field remains relevant and continues to evolve, with great potential for enhancing education and understanding of microbiology through AR technology. Further analysis is needed to understand the specific reasons for the decline in publications, considering various contextual and influencing factors, such as citation count.

The United States emerged as the country with the most cited documents, holding significant influence and relevance in the global scientific community of AR microbiology. Several reasons contribute to this dominance: (1) substantial investments in research and development, including in technology and life sciences, enabling advanced research and high-quality publications; (2) the quality of educational and research institutions attracting top researchers worldwide, contributing to high-quality research output.

This study offers several notable contributions to the field. First, it represents a pioneering effort to systematically map the intersection between augmented reality and microbiology through bibliometric methods. While previous research has explored AR in various educational contexts, few have focused specifically on microbiology, making this analysis both timely and novel. Second, the use of rigorous bibliometric techniques-including performance analysis, co-occurrence network visualisation, and thematic mapping, provides a comprehensive and data-driven overview of the research landscape. Third, the identification of core themes, such as microbiology education and learning enhancement, offers valuable insights for future educational innovation and technological integration. These features collectively enhance the value of the study as a foundation for further exploration and development in this emerging interdisciplinary field.

Implications for Practice and Future Research

The findings of this study have several implications for both educational practice and future scholarly inquiry. The identification of central themes such as "microbiology", "augmented reality", and "learning" emphasises the growing recognition of AR as a transformative tool in science education. Practitioners in microbiology education can leverage AR to create immersive learning experiences that may enhance conceptual understanding, engagement, and student motivation. However, the limited number of studies identified also highlights a need for greater empirical investigation into the pedagogical effectiveness and scalability of AR tools in diverse learning environments.

For future research, there is a substantial opportunity to explore the design, implementation, and long-term impact of AR-based interventions in microbiology curricula. Comparative studies assessing AR versus traditional methods, as well as mixed-methods research exploring learner experiences, would further enrich the field. Additionally, cross-disciplinary collaborations involving educators, technologists, and microbiologists could foster more robust development of AR applications tailored to subject-specific needs. Longitudinal and cross-cultural studies would also be valuable in examining the sustainability and generalisability of AR's educational benefits.

Conclusion

There has been a notable increase in interest and activity in augmented reality within the field of microbiology, particularly in 2022. This surge in interest is evident across various medical disciplines, including medicine, dentistry, and education. The primary focus of AR applications in microbiology has centred on human health, particularly within the medical field. Research has been concentrated on developing AR applications for various areas, such as antimicrobial and anti-infective agents, biofilm studies, ophthalmology, and dentistry.

The United States has emerged as the leading nation in terms of the number of publications and citations in this field. The University of California stands out as the most prolific institution in AR research related to microbiology. It is important to note that this analysis is limited to data available within the Scopus database and may not encompass all relevant publications from other databases. Additionally, the quality of the research has not been explicitly assessed in this analysis. Nevertheless, AR research in microbiology remains a dynamic and rapidly evolving field. There is substantial potential for further exploration and development, making it a valuable area of future research.

Acknowledgements

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References

Alnajdi, S. M. (2022). The effectiveness of using augmented reality (AR) to enhance student performance : using quick response (QR) codes in student textbooks in the Saudi education system. *Educational Technology Research and Development*, *70*(3), 1105–1124. https://doi.org/10.1007/s11423-022-10100-4

Buchner, J., Jeremias, P. M., Kobzare, N., König, L., Oberreiter, S., Reiter, S., & Resch, B. (2021). An Augmented Reality Learning Environment for Informal Geoinformatics Education. *GI_Forum*, *9*(2), 3–17. https://doi.org/10.1553/giscience2021_02_s3

Faith Marcel. (2019). Mobile augmented reality learning objects in higher education. *Research in Learning Technology*, *27*(1–10), 1–10. https://journal.alt.ac.uk/index.php/rlt/article/view/2133/2453

Fidiastuti, H. R., Lathifah, A. S., Amin, M., & Utomo, Y. (2020a). Isolasi dan Karakterisasi Bakteri Indigen Pengurai Lemak pada Limbah Cair Batik Tulungagung. *Bioeksperimen: Jurnal Penelitian Biologi*, *6*(1), 29–35. https://doi.org/10.23917/bioeksperimen.v6i1.10430

Fidiastuti, H. R., Lathifah, A. S., Amin, M., & Utomo, Y. (2020b). Studies of Bacillus subtilis NAP1 to degrade BOD, COD, TSS, and pH: The indigenous bacteria in Indonesia batik wastewater. *Journal of Physics: Conference Series*, *1511*(1). https://doi.org/10.1088/1742-6596/1511/1/012060

Fidiastuti, H. R., Lestari, S. R., Suhadi, S., Prabaningtyas, S., & Setiawan, M. E. (2025). Microbiology literacy mapping: a comprehensive analysis using RStudio. *Asian Education and Development Studies*, *ahead-of-p*(ahead-of-print). https://doi.org/10.1108/AEDS-07-2024-0140

Fleiszig, S. M. J., Kroken, A. R., Nieto, V., Grosser, M. R., Wan, S. J., Metruccio, M. M. E., & Evans, D. J. (2020). Contact lens-related corneal infection: Intrinsic resistance and its compromise. *Progress in Retinal and Eye Research*, *76*(November 2019), 100804. https://doi.org/10.1016/j.preteyeres.2019.100804

Ingrassia, P. L., Mormando, G., Giudici, E., Strada, F., Carfagna, F., Lamberti, F., & Bottino, A. (2020). Augmented reality learning environment for basic life support and defibrillation training: Usability study. *Journal of Medical Internet Research*, *22*(5), 1–8. https://doi.org/10.2196/14910

Jung, T., Dieck, M. C., & Rauschnabel, P. A. (2021). Augmented reality and virtual reality : Changing realities in a dynamic world. *Information Technology & Tourism*, *23*(4), 637–639. https://doi.org/10.1007/s40558-021-00212-7

Lorek, S., & Spangenberg, J. H. (2014). Sustainable consumption within a sustainable economy – beyond green growth and green economies. *Journal of Cleaner Production*, *63*, 33–44. https://doi.org/https://doi.org/10.1016/j.jclepro.2013.08.045

Luo, W., & Cheng, J. (2022). Transition to sustainable business models for green economic recovery: role of financial literacy, innovation and environmental sustainability. *Economic Change and Restructuring*, *0123456789*. https://doi.org/10.1007/s10644-022-09408-1

Nuanmeesri, S. (2018). The augmented reality for teaching Thai students about the human heart. *International Journal of Emerging Technologies in Learning*, *13*(6), 203–213.

https://doi.org/10.3991/ijet.v13i06.8506
Obaideen, K., Shehata, N., Sayed, E. T., Abdelkareem, M. A., Mahmoud, M. S., & Olabi, A. G. (2022). The role of wastewater treatment in achieving sustainable development goals (SDGs) and sustainability guideline. *Energy Nexus*, *7*(July), 100112. https://doi.org/10.1016/j.nexus.2022.100112
Pathania, M., Mantri, A., Prit, D., Chander, K., & Singh, P. (2021). A Chronological Literature Review of Different Augmented Reality Approaches in Education. *Technology, Knowledge and Learning*, *0123456789*. https://doi.org/10.1007/s10758-021-09558-7
Rachman, F. H., Rahayu, L. S., Suhadi, , & Sitoresmi, P. (2024). Developing microbiology literacy in biology education college: future teacher candidates. *Journal of Microbiology & Biology Education*, *0*(0), e00035-24. https://doi.org/10.1128/jmbe.00035-24
Rozana, K., Prabaningtyas, S., & Widyatama, D. R. (2023). Distribution and biodegradation analysis of polyvinyl chloride microplastic by indigenous bacteria isolated from Supit Urang Landfill, Malang, Indonesia. *Biodiversitas*, *24*(7), 3853–3859. https://doi.org/10.13057/biodiv/d240724
Timmis, K. (2023). A Road to Microbiology Literacy (and More): an Opportunity for a Paradigm Change in Teaching. *Journal of Microbiology & Biology Education*, *24*(1). https://doi.org/10.1128/jmbe.00019-23
Timmis, K., Cavicchioli, R., Garcia, J. L., Nogales, B., Chavarría, M., Stein, L., McGenity, T. J., Webster, N., Singh, B. K., Handelsman, J., de Lorenzo, V., Pruzzo, C., Timmis, J., Martín, J. L. R., Verstraete, W., Jetten, M., Danchin, A., Huang, W., Gilbert, J., … Harper, L. (2019). The urgent need for microbiology literacy in society. *Environmental Microbiology*, *21*(5), 1513–1528. https://doi.org/10.1111/1462-2920.14611
Timmis, K., Timmis, J., & Jebok, F. (2020). The urgent need for microbiology literacy in society: children as educators. *Microbial Biotechnology*, *13*(5), 1300–1303. https://doi.org/10.1111/1751-7915.13619
Tom, A. P., Jayakumar, J. S., Biju, M., Somarajan, J., & Ibrahim, M. A. (2021). Aquaculture wastewater treatment technologies and their sustainability: A review. *Energy Nexus*, *4*(July), 100022. https://doi.org/10.1016/j.nexus.2021.100022
Uriarte-Portillo, A., Ibáñez, M. B., Zataraín-Cabada, R., & Barrón-Estrada, M. L. (2022). Higher Immersive Profiles Improve Learning Outcomes in Augmented Reality Learning Environments. *Information (Switzerland)*, *13*(5), 1–11. https://doi.org/10.3390/info13050218
Vandegrift, R., Bateman, A. C., Siemens, K. N., Nguyen, M., Wilson, H. E., Green, J. L., Van Den Wymelenberg, K. G., & Hickey, R. J. (2017). Cleanliness in context: reconciling hygiene with a modern microbial perspective. *Microbiome*, *5*(1), 76. https://doi.org/10.1186/s40168-017-0294-2
YAPICI, İ. Ü., & KARAKOYUN, F. (2021). Using Augmented Reality in Biology Teaching. *Malaysian Online Journal of Educational Technology*, *9*(3), 40–51. https://doi.org/10.52380/mojet.2021.9.3.286

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Integrating Vietnam's Living Heritage into STEM Education: The Case of Vietnamese Conical Hat

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Abstract

This study presents an innovative integration of STEM education with the preservation of Vietnam's living heritage through the traditional craft of the Vietnamese conical hat at Gia Thanh Secondary School. The project aims to enhance student engagement in STEM by embedding the conical hat's cultural production process into Mathematics, Science, and Engineering lessons. Over 200 students participated in hands-on activities by applying geometric principles to design the conical hat, exploring material science using natural materials, and learning engineering concepts through traditional crafting methods. Overall, 85% of students reported that their interests had increased in STEM subjects, as measured by performance in geometry (95% success) and material science (80% engagement). Furthermore, the initiative connected students with local artisans, fostering cultural pride and raising awareness of the economic and cultural importance of the conical hat. By integrating heritage preservation with STEM education, this project demonstrates a replicable model for enriching STEM learning while maintaining local cultural traditions.

Keywords: Living Heritage; Nón Lá; STEM Education; Student Engagement; Vietnam

Introduction

Vietnam is renowned for its rich cultural heritage, with a diversity of practices and traditions that span centuries. Among its most iconic intangible cultural heritage is the traditional craft of *Nón Lá* (Vietnamese conical hat). However, like many traditional crafts in Vietnam, *Nón Lá* is at risk of decline due to the impacts of modernisation, urbanisation, and industrialisation (Nam & Thanh, 2024; Son, 2023). This has raised concerns about the preservation of such cultural practices and the need for new strategies that can sustain their relevance in contemporary society (Phan Ngoc, 1998).

The Convention for the Safeguarding of Intangible Cultural Heritage, adopted by UNESCO in 2003, underscores the importance of protecting such intangible heritage through education and the active involvement of local communities (UNESCO, 2003). Vietnam has been a signatory to this convention and has made significant efforts to safeguard its cultural heritage through initiatives that engage both communities and schools (Living Heritage

Entity, 2022). However, the challenges faced by communities such as Van Phuc Silk Village demonstrate that cultural heritage preservation requires more than just governmental support—it also necessitates the active participation of local artisans and innovative methods that integrate heritage into the educational system (Son, 2023).

Previous studies have shown that community involvement plays a vital role in the conservation of cultural heritage, particularly in preserving the knowledge and skills that are passed down through generations (Nam & Thanh, 2024). Despite these efforts, there is still a gap in integrating such heritage into formal academic subjects, particularly in STEM education (Nam & Thanh, 2024; Nguyen et al., 2020; Vuong et al., 2020).

The introduction of STEM education as a framework for cultural heritage preservation offers a unique solution to this gap (Wang Yuecheng, 2023). By integrating cultural heritage into STEM lessons, students can engage in hands-on learning experiences that not only teach scientific and engineering concepts but also foster an appreciation for their cultural identity(Bertoni & Peverada, 2023; Binbin et al., 2024; Sang & Yang, 2023).This approach aligns with the goals of the 2003 UNESCO Convention, which advocates for educational strategies that raise awareness of intangible cultural heritage among younger generations.

This study proposes an innovative model that integrates the traditional craft of *Nón Lá* into the STEM curriculum at Gia Thanh Secondary School. By using the craft as a medium for teaching geometry, engineering, and material science, this study aims to identify *Nón Lá* as a living heritage, investigate its STEM aspects, design STEM lessons centred around *Nón Lá* for secondary students, and foster cultural pride and awareness among the younger generation.

Methodology

The project involved over 200 students ages 12-15 at Gia Thanh Secondary School. The selection of students was voluntary, but their participation in cultural activities and prior knowledge of the conical hat craft was minimal. Teachers and local artisans from Gia Thanh, recognised for their expertise in crafting *Nón Lá*, were key collaborators.

The research was structured into five phases to explore the integration of Vietnam's *Nón Lá* into STEM education. The methodology followed a systematic approach to ensure that cultural preservation and effective STEM education were achieved.

The first phase focused on recognising *Nón Lá* as a vital part of Vietnam's intangible cultural heritage. A survey was conducted among Gia Thanh School's students to assess their awareness and attitudes towards *Nón Lá*. The goal was to determine whether the students considered *Nón Lá* as a part of their cultural identity, understood its historical importance, and recognised its diminishing role in modern life. The second phase explored the scientific, technological, engineering, and mathematical elements in the making of *Nón Lá*. The objective was to uncover how traditional craftsmanship could be broken down into STEM-related topics, such as the geometry of the hat, the materials used, and the engineering principles involved in its design. Table 1 show the design of STEM activities in this study. Based on the STEM aspects identified, the third phase involved the design of STEM activities that incorporate *Nón Lá* craftsmanship into educational lessons. These activities were designed to engage the students on scientific and mathematical principles application in the production of *Nón Lá*. The performance of students was measured by the assessment questions. The fourth phase focused on gathering and analysing data from the implemented STEM activities and pedagogical experiments. Surveys, observational data, and student performance assessments were utilised to measure the success of integrating *Nón Lá* into STEM education. In the final phase, the research reflected on the overall outcomes of the study. This included an assessment of both the educational impact on students and the broader cultural impact in terms of raising awareness about *Nón Lá* as an important element of Vietnamese heritage.

Table 1. Designing and Implementing STEM Activities

STEM lesson	Subject	Vietnamese Curriculum Objectives	NGSS DCI and SEP[1]	STEM Activity
Geometry and Measurement	Maths (Grades 6-9)	Maths: Focus on applying geometric formulas to real-world problems	DCI: 6. G.A. (Geometry: Solve real-world mathematical problems involving area, surface area, and volume); SEP: Using Mathematics and Computational Thinking	Calculate the surface area and volume of *Nón Lá* using cone formulas. Create models to visualize and compare surface areas and volumes.
Material Properties	Science (Grades 6-9)	Science (Grades 6-9): Investigate material properties like flexibility and durability.	DCI: PS1.A (Structure and Properties of Matter); SEP: Planning and Carrying Out Investigations	Investigate the properties of bamboo and palm leaves used for *Nón Lá* construction. Test the tensile strength and flexibility of different materials.
Design and Technology	Technology (Grades 6-9)	Technology (Grades 6-9): Apply engineering principles to construct items, understanding the tools used in traditional crafts	DCI: ETS1.B (Developing Possible Solutions); SEP: Constructing Explanations and Designing Solutions	Design and build a model *Nón Lá* using bamboo skewers and string, focusing on structural integrity and proposing design improvements.
Material Treatment	Science (Grades 6-9)	Science (Grades 6-9): Explore chemical reactions and material preservation	DCI: PS1.B (Chemical Reactions); SEP: Planning and Carrying Out Investigations	Experiment with different chemical treatments for leaves and observe changes in texture, colour, and durability.

[1] NGSS: Next Generation Science Standards, DCI: Disciplinary Core Ideas, SEP: Science and Engineering Practices (SEP)

Application of Technology in Craft	Technology (Grades 6-12)	Technology (Grades 6-12): Understand how to use tools and technology in traditional crafts	DCI: ETS1.A (Defining Engineering Problems); SEP: Using Mathematics and Computational Thinking	Explore traditional and modern tools for crafting *Nón Lá*. Compare traditional methods with modern technologies to enhance durability and efficiency.
Virtual Reality (VR)	Technology (Grades 6-12)	Use virtual platforms to simulate processes and enhance technological understanding	DCI: ETS1.A (Defining Engineering Problems); SEP: Using Mathematics and Computational Thinking	Use VR to explore *Nón Lá* construction. Apply coding skills to simulate robots performing tasks related to the geometry of *Nón Lá.*

Results and Discussion

Identifying *Nón Lá*–Conical Hat as a Living Heritage

The first phase of this research aimed to assess the current perceptions and awareness of *Nón Lá* as a cultural heritage element among students at Gia Thanh School. A structured survey was administered to 224 students to evaluate their awareness, interests, and practical use of *Nón Lá* in daily life. The survey revealed that nearly 70% of students expressed no interest or understanding of the traditional craft, whereas this was significant given the cultural importance of *Nón Lá* in their local community. In terms of practical usage, 90% of students reported not using *Nón Lá* at home for tasks like gardening or farming, opting instead for fabric hats or modern alternatives. Additionally, observations showed that 100% of students commuting by bicycle wore fabric hats or used umbrellas, indicating that *Nón Lá* no longer plays a role in their daily routines.

The data also revealed differences in interest levels across different grades, with Grade 6 students showing the highest level of disinterest (45 students). Overall, the findings discovered that *Nón Lá* became irrelevant to the younger generation in Gia Thanh, signalling a concerning decline in cultural engagement. The lack of practical use and emotional connection to *Nón Lá* was the cause of a diminishing cultural significance, raising concerns about the future of this traditional craft. To address this, an innovative method by integrating *Nón Lá* into STEM education should be explored to rekindle interest and ensure the preservation of this important cultural heritage for future generations.

The STEM Aspect of *Nón Lá*

The diagram depicts the mathematical dimensions of a traditional Vietnamese *Nón Lá*. In terms of geometry, the hat has a conical shape, and the key measurements include: (1) Bottom diameter (D): The diameter of the base is typically around 45 cm, which forms the circular base of the cone; (2) Height (H): The vertical height of the cone is approximately 25 cm; and (3) Slant height (L): The slant height, which is the distance from the tip of the cone to the edge of the base, is 33 cm. The base is represented as a circular arc with evenly distributed rims that emulate the real-life structure of a *Nón Lá*. In this geometric model, each rim is modelled as an ellipse section, simulating the horizontal bamboo rings. The conical hat leaves are made from *buông* leaves or palm leaves.

The materials and tools for making the conical hat include palm leaves, hat mould, hat rims, areca sheath, steel needles, and thread. The frame is made from bamboo, consisting of eight spokes and 16 grooves. The diameter of the largest hat rim is 40-50 cm, the length of the spokes is 24-27 cm, and the distance between each rim is 2 cm. The rims are sequentially arranged in the conical hat mould from the largest to the smallest, with each rim's connection point on the mould staggered. The largest rim is made from smooth, rounded diễn bamboo, which is thicker to ensure the hat is sturdy and durable. The rims must be flat, without rough or uneven surfaces, and there are a total of 15 rims.

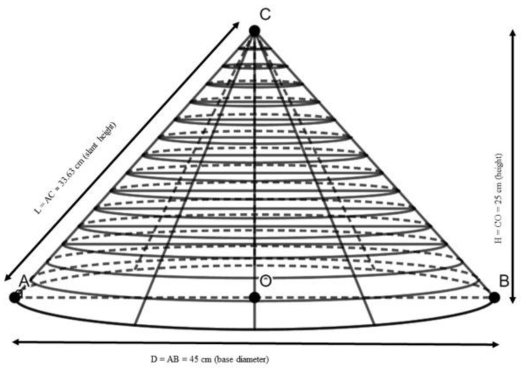

Figure 1: Geometric Model of the Traditional Vietnamese Conical Hat (Nón Lá)

The Process of Making a *Nón Lá*

Step 1: Selecting, Rolling, and Ironing the Leaves

The selected leaves must be flat, smooth, and not brittle or torn. While ironing the leaves, it was crucial to control the heat so the leaves did not burn or become too soft, ensuring they achieved the necessary durability and flexibility for making the hat.

Step 2: Assembling the Hat Frame - Making the Rims

The hat frame was made from bamboo or wood, consisting of eight spokes and 16 grooves. The diameter of the hat rim ranges from 40-50 cm, the length of the spokes is 24-27 cm, and the distance between the rims is 2 cm. The rims were split into small bamboo slats, shaved smooth and round. These rims were sequentially arranged in the conical hat frame from the largest to the smallest, with each rim's connection pointed on the mould and staggered to be more stable.

Step 3: Assembling the Hat

The hat was assembled in three layers: (1) The inner layer, with the right side of the leaf facing inward, was attached tightly to the frame; (2) A layer of dried mould tree bark (flattened and dried) was spread evenly over the frame; (3) The outer layer of beautiful leaves was spread over the mould layer, ensuring the frame is completely covered. To prevent the leaves from shifting, two strings were used to hold the leaves in place.

Step 4: Sewing the Hat

The hat was sewn using transparent white nylon thread, ensuring the thin and delicate stitching characteristic of the conical hat. The leaves must remain in place, and the stitches must be even and neat. The sewing process started from the third rim down to the bottom of the hat's brim.

Step 5: Securing the Hat

The securing process utilised red nylon thread and two bamboo steel wires, with one layer of tree bark placed between the two wires. Securing the hat helps reinforce the rim, making it stronger and more durable.

Step 6: Threading the Straps and Finishing the Tip

Threading the straps: The inner part of the hat (around the 3rd, 4th, and 5th rims from the largest rim up to the tip) is where the craftsman uses a large curved needle and yarn to symmetrically tie and attach the hat straps. The threading is usually done with colourful yarns like purple, peach pink, or light green to add a touch of vibrancy and help the hat sit securely on the head.

Finishing the tip: On the outside of the hat (at the smallest circle of the conical shape), the craftsman used white nylon thread to sew neat, tight stitches up to the tip. This tight stitching ensures that water does not leak into the hat and strengthens the tip, making it firm and durable.

After the hat was completed, the craftsman applied a coat of resin mixed with gasoline, brushing it over the surface of the hat twice. This layer helps the hat become stronger, more durable, and more beautiful. A well-made conical hat is defined by even stitches, tight needlework, smooth leaves, as well as round, smooth rims.

Pedagogical Experiments

Based on the pedagogical experiments conducted at Gia Thanh Secondary School, the results demonstrated a high level of student engagement and successful learning outcomes in the integration of STEM principles with the cultural heritage of *Nón Lá*. In the Geometry and Measurement lesson of the 224 students, 95% (213 students) successfully calculated the surface area and volume of the conical hat, with 90% showing high engagement in both mathematical and cultural aspects of the lesson. Only 5% of students required assistance, and another 5% struggled with the concepts, highlighting the overall effectiveness of the lesson.

In the Material Properties lesson, 80% of students successfully identified the properties of the materials used in *Nón Lá* making, with 95% engaging enthusiastically in material testing. This lesson sparked interest in applying traditional materials, like bamboo and palm leaves, to modern technologies. The Design and Technology lesson also showed positive results, with 75% of students successfully constructing a model conical hat and 85% deeply engaged in the design challenge. However, 20% of students required structural revisions to their models, and 5% were unable to complete the task, indicating room for further support and refinement of the lesson structure. Table 2 show the Summary of Pedagogical Experiment Results.

Table 2. Summary of Pedagogical Experiment Results

STEM Lesson	Key Learning Outcome	Student Performance
Geometry & Measurement	Calculated the surface area and volume of a cone	95% (213/224) were successful; 90% were highly engaged; 5% needed assistance; 5% struggled
Material Properties	Identified and tested traditional materials (bamboo, palm leaves)	80% correctly identified properties; 95% enthusiastically engaged in testing
Design & Technology	Constructed model of *Nón Lá*; applied engineering design principles	75% successfully built models; 85% were highly engaged; 20% needed revisions; 5% did not complete the task

These findings suggest that integrating cultural elements into STEM education can significantly enhance both student engagement and learning outcomes, while also fostering an appreciation for traditional craftsmanship.

Reflection and Cultural Impact

Based on the data from the pedagogical experiments and survey results, it is evident that integrating the *Nón Lá* into STEM education has had a notable impact on both cultural preservation and student engagement. According to the survey conducted with 224 students at Gia Thanh

Secondary School, approximately 70% of the students expressed little to no interest or understanding of the *Nón Lá*, indicating a significant decline in the connection between the younger generation and this cultural artifact. Only 10% of students occasionally used the *Nón Lá* for daily activities, such as helping with farming or gardening, while 90% preferred modern alternatives like fabric hats. This trend highlights the urgency of educational interventions to reconnect students with their cultural heritage.

In response, the STEM-based lessons demonstrated promising results. For example, in the geometry and measurement lesson, 95% of students accurately calculated the surface area and volume of the *Nón Lá*, and 90% were highly engaged in the activity, appreciating both its cultural and mathematical relevance. Similarly, 80% of students correctly identified the material properties of the bamboo and palm leaves used in *Nón Lá* making, with 95% showing high engagement in the hands-on testing. These findings suggest that integrating cultural elements like the *Nón Lá* into STEM education can significantly boost student interest in both STEM subjects and traditional crafts, thus ensuring the preservation of this important cultural heritage.

Discussion

The integration of local cultural artifacts, such as the Vietnamese *Nón Lá*, provides a meaningful context for STEM education. By connecting traditional knowledge systems with modern scientific thinking, students not only engage more deeply in mathematical reasoning but also develop a stronger appreciation for their cultural identity. This approach aligns with global educational trends that encourage culturally responsive pedagogy, particularly within the framework of the NGSS, DCI, and SEP. While the study is limited in scope, it offers a promising model for incorporating indigenous and local knowledge into formal STEM curricula. Future research should investigate the long-term effects of such integration on students' attitudes toward heritage preservation and their interdisciplinary competencies.

Conclusion

This study demonstrates the potential of integrating Vietnam's living heritage into STEM education, using the *Nón Lá* as a case study. Through a series of STEM-based lessons delivered to over 200 students at Gia Thanh Secondary School, the project effectively combined cultural preservation with the enhancement of STEM learning outcomes. The results showed that over 85% of students reported increased interest in both STEM subjects and the *Nón Lá* as a cultural artifact, following their engagement in hands-on activities involving geometry, material science, and engineering.

While the short-term data showed high levels of student interest and participation, particularly in relation to both STEM topics and the cultural artifact, these findings do not allow for definitive conclusions regarding the broader impact on cultural preservation. The project highlights a promising approach to embedding traditional knowledge into modern education. It is hoped that similar initiatives may contribute to raising cultural awareness and fostering appreciation for intangible heritage within contemporary STEM contexts.

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References

Bertoni, M., & Peverada, E. (2023). Engineering design for the cultural world heritage: reflections from the implementation of a challenge-based learning approach. *Swedish Engineering Education Development Conference*. https://sdgs.un.org/goals

Binbin, T., Sereerat, B., Songsiengchai, S., & Thongkumsuk, P. (2024). The

Development of Intangible Cultural Heritage Curriculum Based on Experiential Learning Theory to Improve Undergraduate Students Understanding in Intangible Cultural Heritage. *World Journal of Education*, *14*(1), 43. https://doi.org/10.5430/wje.v14n1p43

Living Heritage Entity. (2022). *Basic Texts of the 2003 Convention for the Safeguarding of the Intangible Cultural Heritage 2022 Edition*.

Nam, N. T., & Thanh, N. N. (2024). The role of local communities in the conservation of cultural heritage sites: A case study of Vietnam. *Journal of Asian Scientific Research*, *14*(2), 179–196. https://doi.org/10.55493/5003.V14I2.5057

Nguyen, T. P. L., Nguyen, T. H., & Tran, T. K. (2020). STEM education in secondary schools: Teachers' perspective towards sustainable development. *Sustainability (Switzerland)*, *12*(21), 1–16. https://doi.org/10.3390/su12218865

Phan Ngoc. (1998). *Vietnam Cultural Identity*. Literature Publishing House.

Sang, Y., & Yang, J. (2023). *Highlights in Art and Design Research on Cultural tourism Resources of Developing "Intangible Cultural Heritage"- Taking Huaihe Culture as an example*. *2*(2), 66.

Son, N. H. (2023). Challenges in conserving Intangible Cultural Heritage in Vietnam as seen from the Van Phuc Silk Village. *IKAT: The Indonesian Journal of Southeast Asian Studies*, *6*(2), 118. https://doi.org/10.22146/ikat.v6i2.73993

UNESCO. (2003). *The Convention for the Safeguarding of the Intangible Cultural Heritage*.

Vuong, Q.-H., Pham, T.-H., Tran, T., Vuong, T.-T., Nguyen, M.-C., Nguyen, K.-L. P., La, V.-P., & Ho, M.-T. (2020). *STEM education and outcomes in Vietnam: Views from the social gap and gender issues*.

Wang Yuecheng. (2023). How to Integrate Traditional Culture into STEM Teaching. *Frontiers in Educational Research*, *6*(7). https://doi.org/10.25236/fer.2023.060705

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Research Paper | Open Accsess

Preliminary Study on Game-Based Learning to Promote Javan Leopard Conservation: Perspectives from Prospective Biology Teachers

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Abstract

Research on game-based learning has been widely conducted to support biology education in the classroom. Thistype of learning should also have an additional impact on students, one of which is introducing endangered species, such as the Javan leopard (Panthera pardus melas). This study explores the initial stage of developing Game-Based Learning (GBL) media and its impact on prospective biology teachers' interest, attitude, andknowledge regarding Javan leopard conservation. The research method used a quantitative and qualitative approach, with asurvey comprising both open and closed-ended questions to assess the responses of prospective biology teachers to the biology game application focused on ecological communities. Interest was measured on a Likert scale; attitudes were measured through multiple-choice and agreement-scale questions; and knowledge was assessed through multiple-choice and true/false questions, while open-ended questions were applied for suggestions and recommendations from GBL. The respondents were 108 students who had previously tested the developed application. In the data analysis, descriptive statistical methods were used to interpret quantitative data, while qualitative analysis was conducted using word clouds to depict the answers of prospective biology teacher students in open-ended questions. The demographic data revealed that 73% of students typically play games for less than 1 hour per week, 72% play online games, and adventure is the most frequently played genre. Additionally, 92% of students had never played a game related to leopards before, and only about 27.1% of students had prior knowledge about leopards, mostly from their teachers at school. After using the application, 68% of students expressed increased interest in leopard conservation, improved knowledge, and demonstrated a positive attitude. Furthermore, 88% of students felt that the game helped raise their awareness of leopard conservation. This study concludes that game-based learning, which integrates information about endangered species like the Javanleopard, has enormous potential to support biology education and raise awareness of biodiversity conservation.

Keywords: Biology Education; Javan Leopard; Local Species; Conservation Learning

Introduction

One of the species that needs special attention from all parties, including in the field ofeducation in Indonesia, is the Javan leopard. After the extinction of tigers from Java Island in the 1980s, the endemic and critically endangered Javan leopard (*Panthera pardus melas*) became the only major carnivore left on the island (Ario, Mercusiana, et al., 2022; Ariyanto et al., 2024; Wibisono et al., 2018). Threats to the Javan leopard also occur frequently, such as illegal hunting, habitat destruction, fragmentation, and conflict between humans and illegal wildlife trade (Ario, Murdyatmaka, et al., 2022; Gomez & Shepherd, 2021). The sharp increase in human-to-Javan leopard conflicts due to habitat degradation that has continued in the last 15years urges urgent efforts to restore habitats and manage conflicts to create a balance between wildlife conservation and community needs (Gunawan et al., 2017). An important analysis of population, distribution, and occupancy has been carried out as a recommendation from biological, policy, and conservation aspects for the survival of leopards on the island of Java (Ario, Mercusiana, et al., 2022). Based on this, various efforts are needed in the conservation of leopards, one of which can be done through education.

Education has an important role, as it significantly influences local attitudes towards leopard conservation (Rani et al., 2024). This is also in line with the research conducted by Dhungana et al. (2022), experiences with tigers or leopards, and education make a significant positive contribution to attitudes towards tigers, leopards, tiger conservation, and leopard conservation. Another example is in the case of snow leopards in India for conflict mitigation, especially in capacity building and awareness programmes, one of which is also carriedout through education (Moheb et al., 2022). The importance of active environment-based education towards action and involvement of various parties in order to create an effective generation of environmentalists (Alamshoev et al., 2024). Based on various experiences about the role of education for leopards, it is also important to be initiated to be carried out in Indonesia.

Studying the role of biology education in preserving Javan leopards in Indonesia is crucial because it can increase awareness, improve knowledge, and develop positive attitudes toward conservation. Education plays an essential role in making individuals environmental stewards (Altassan, 2023; Goodale et al., 2025; Yadav et al., 2022). However, little research has been done on the role of biology education in acquiring knowledge and the involvement of students in Javan leopard conservation. So far, research on Javan leopard education has only led to aspects of knowledge, perception, and conflict in society in general (Dewanti & Marhaento, 2021; Partasasmita et al., 2016).

By filling this knowledge gap, the research can uncover how conservation can be associated with biology education, identify sound practices in instruction, and suggest curriculum changes considering the protection of local biodiversity. The study will also assist in evaluating whether current teaching approaches prepare future biology instructors to advocate for Javan leopard conservation. Doing so will assist in educational development and conservation so that students and teachers will be active participants in protecting Indonesia's unique wildlife.

Education can play a role in communicating and teaching about the value of threatened species (Robinson et al., 2018). Biodiversity conservation education is the key to building a society that cares about and actively participates in nature conservation efforts; therefore, it needs to be an integral part of formal education (Børresen et al., 2023). Game-Based Learning has also been used to study the biology, ecology, and conservation of jaguar species in South America (Almeida et al., 2024). As for Indonesia, several GBLs have also been developed based on the use of local potential endemic species in each region, such as in Papua (Yuliawan et al., 2022) and Borneo (Ramadiani et al., 2021). Game-Based Learning has also been used as an effective learning method in biodiversity conservation among Indonesia’s secondary school students, with significant knowledge improvement results (Wijoyo et al., 2025). Therefore, educational efforts through meaningful learning are needed that integrate current technological advances in Javan leopard conservation efforts, which is Game-Based Learning.

The use of GBL has been widely carried out in improving the quality of learning in the classroom. As interest in using 3D games for education increases, more and more research is trying to integrate gamification elements in learning to increase engagement and improve student learning outcomes (Sanzana et al., 2024; Situmorang et al., 2024). GBL activities can also have a positive and fun impact on biology learning (Jones et al., 2019). The advantage of GBL is that students can interact, solve problems, and assess their actions, which can help them find many solutions to a single problem (Cosme et al., 2020).

In a systematic literature review that has been conducted, the application of digital games in biology learning can increase student engagement, foster social interaction through collaboration or discussion, and offer personalised and adaptive learning experiences that are tailored to individual needs and abilities, which ultimately motivates students to actively participate in the learning process (Situmorang et al., 2024). Studies show that well-designed educational games, combining learning theory and elements of entertainment games, can help develop students' 21st-century skills (Qian & Clark, 2016). If it is associated with games that explicitly discuss conservation, it is currently popular and evolving (Sandbrook et al., 2015; Tan et al., 2018). In order to design this GBL, it is necessary to understand the context of the material itself, learning objectives, learning tasks, and the accuracy of the technology used so that it can follow the expected learning outcomes.

GBL can also increase the understanding of biodiversity and motivation of students (Meekaew & Ketpichainarong, 2018). Relating to biodiversity is also important in understanding the local species found around the school environment. Teachers who have more knowledge about local species can have more confidence during biology learning, especially about wildlife (Skarstein & Skarstein, 2020). Emphasis on the role of teachers in imparting species knowledge to students and increasing public awareness of native species is a part of general education for biodiversity conservation (Gerl et al., 2021). GBL is effective in raising awareness about biodiversity threats such as invasive species (Miralles et al., 2021). Moreover, it has another impact on students, one of which is to introduce endangered local species such as the Javan leopard.

The role of education through GBL can contribute to the conservation of the Javan leopard. It is also expected that there will be more prospective teachers who are aware and concerned about the existence and conservation of leopards. Besides that, they can also help various Javan leopard research scientists as a liaison to deliver the results of their research to students and increase the awareness of Javan leopard conservation. This is in line with research conducted by Wright et al., (2021), showing that collaboration between teachers and scientists, which allows the use of real data from the local environment, strengthens learning in conservation education.

The problem found in the classroom is that only a few students relate their assignments in the conservation biology course to local species such as leopards. This issue may affect their interest, attitudes, and knowledge about leopards as future biology teachers. The low interest of students in Javan leopards can be seen from the lack of involvement in discussions and assignments, as well as limited participation in field studies related to local biodiversity in the classroom. If left unaddressed, these issues can affect their abilities as aspiring biology teachers to foster awareness and appreciation for local wildlife conservation among their students (Palmberg et al., 2018). Students also lack concern and responsibility in understanding and supporting efforts to preserve this species. Lack of knowledge can be reflected through conceptual errors, ignorance of the conservation status of leopards, and the inability to link their ecological role to ecosystem balance. If this knowledge is not strengthened, students as prospective biology teachers may have difficulty in teaching the importance of conservation and knowledge about local species to their students (Skarstein & Skarstein, 2020). Therefore, it is also important to prepare prospective biology teachers who know about the conservation of local species, one of which is the Javan leopard.

Prospective biology teachers who understand Javan leopard conservation are also expected to provide new insights into biology learning that emphasizes the introduction of localspecies. The aim of this study is to explore the initial stage of developing Game-Based Learningmedia and its impact on prospective biology teachers' interest, attitude, and knowledge regarding Javan leopard conservation. In addition, it is also expected to provide benefits both practically and theoretically, especially in biology learning related to biodiversity conservation. It is hoped that this research can also contribute to and benefit the Indonesian Biodiversity Strategy Action Plan (IBSAP) (Ministry of Environment and Forestry, 2024), especially in national target 16, at point 16.1 on increasing biodiversity knowledge through formal and non-formal education.

Methodology

Participants

The research used a quantitative approach, with a survey comprising both open and closed-ended questions to assess the responses of prospective biology teachers to the biology game application focused on ecological communities. The number of respondents was 118 students who had previously tested the developed application. All these respondents are prospective biology teacher students enrolled in Conservation Biology courses in the Biology Education study programme, Siliwangi University.

Questions related to respondents' demographics, experience playing games, interest inleopard conservation, knowledge about leopards, attitudes towards leopard conservation, and recommendations for games that have been made and game recommendations related to Javanleopards in the future. The administered questionnaire underwent prior validation through expert review, conducted by two lecturers specializing in conservation biology education, achieving an average validation score of 0.95. Questions were created using open and closed questionnaires that referred to several sources. The questionnaire sheet is designed to measure students' interest, attitudes, and knowledge regarding Javan leopard conservation through Game-Based Learning.

Questions about several types of games were adapted from Qaffas (2020). Interest was assessed using a Likert scale, comparing students' enthusiasm before and after playing the game. Questions about attitudes and knowledge were developed from Barthwal and Mathur (2012); Dhungana et al., (2022); and Uduman et al., (2022). Attitudes were measured through multiple-choice and agreement-scale questions, evaluating their willingness to support conservation efforts and their views on the coexistence of humans and Javan leopards. Meanwhile, knowledge was tested using multiple-choice and true/false questions, covering topics such as threats to the species, its ecological role, and conservation programmes.

These instruments provide a comprehensive understanding of how Game-Based Learning influenced students' awareness and perception of Javan leopard conservation. After that, analysis was carried out using descriptive statistics, as well as qualitative analysis using word clouds (Pro Word Cloud from add-ins in MS Office) based on answers about from prospective biology teacher students on open questionnaires.

Results and Discussion

Results

Demographics Information

Based on the demographic information of the respondents in Table 1, it could be seen that prospective biology teachers who filled in were dominated by women (90.7%), with the frequency of playing games being less than 1 hour (72.9%). 72% of respondents preferred to play online games with the adventure genre (27.1%), while 92.4% of respondents had played games related to the leopard species. Some games that have leopard characters are included Mobile Legend, Oasis, Temple Run, and Ultimate Leopard Simulation (smartphone-based games)

Table 1. Demographics Inform

Gender	**N**	**Percentage (%)**	**Game Genre**	**N**	**Percentage (%)**
Male	11	9.3	RPG	17	14.4
Female	107	90.7	FPS	3	2.5
Gaming Frequency (in a week)	**N**	**Percentage (%)**	Adventure	32	27.1
			Simulation	28	23.7
Less than 1 hour	86	72.9	MOBA	29	24.6
1-3 hours	24	20.3	Other:	9	7.6
4-6 hours		4.2	**Ever played a game related to leopards**	**N**	**Percentage (%)**
More than 6 hours		2.6			
Type of network	**N**	**Percentage (%)**			
Online	85	72.0	Yes	109	92.4
Offline	33	28.0	No	9	7.6

Game-Based Learning using Leopards

The GBL that was created aims to observe ecological events related to populations and food chains, which initially did not use species native to Indonesia, namely lions (*Panthera leo*). In fact, in terms of morphology, it is almost similar because it belongs to the same family (Felidae), so it is recommended to use local species such as the Javan leopard (*Panthera pardus melas*) in addition to that other species such as Javanese rabbits and grasses are also introduced in the GBL. This graphic basis was developed using Blender application, which is also widely used for other biology learning (Suprapto et al., 2019). Figure 1 is the basic shape of a leopard created using Blender application which later be used for the game in Figure 2.

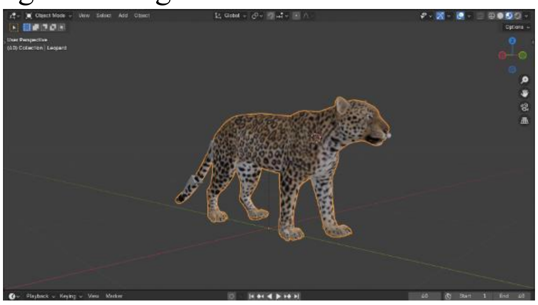


Figure 1. 3D Structure of a Leopard Created through a 3D Blender

Figure 1 was the display of a Javan leopard designed using Blender application. The design was made as similar as possible to the Javan leopard based on its morphological structure.

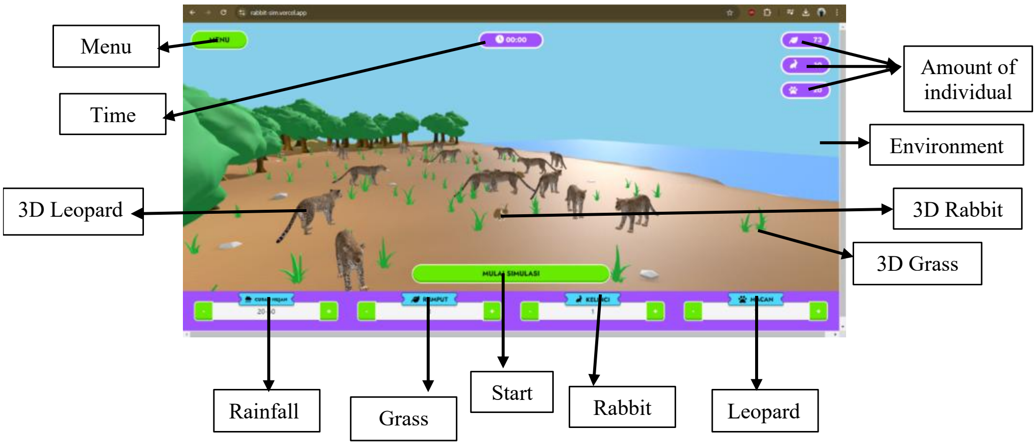


Figure 2. View of the Game-Based Learning Application containing Javan Leopards and Their Preys (Javanese Rabbits)

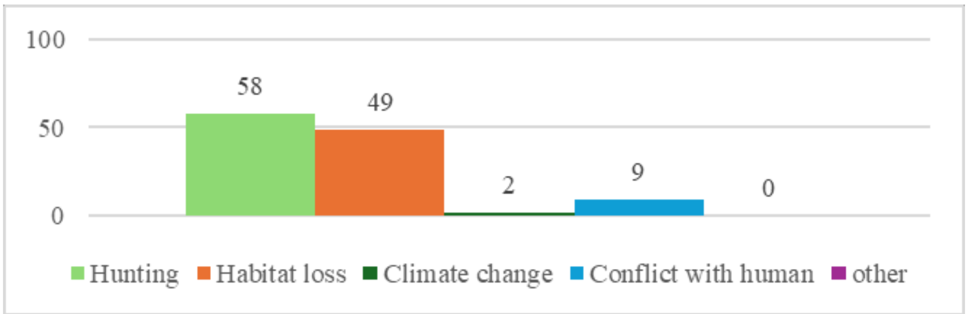


Figure 3. The Answers to The Biggest Threat to Leopard Conservation, according to Prospective Biology Teachers

Figure 2 was a display image of the entire application developed. The image depicted the design of a community in an ecosystem with a few species, as an image of the sustainability of each existing species.

Knowledge, Interests, and Attitudes towards Leopards' Threat and Conservation

The first question related to knowledge about leopards was the biggest threat to the Javan leopard in Indonesia. Based on the answers from prospective biology teacher students, the answers were in Figure 3 as follows:

Based on the answers submitted by prospective biology teacher students, the biggest threats to leopards were hunting with 58 answers (49.1%), habitat loss with 49 answers (41.5%), climate change with 2 answers (1.7%), and conflict with humans with 9 answers (7.6%). Based on the references studied, the main cause of the threat to the Javan leopard was the loss of Javan leopard habitat (As'ary et al., 2023; Gomez & Shepherd, 2021; Gunawan et al., 2017). The differences between student perceptions and scientific evidence indicated the need for improvements in conservation education, especially in providing a deeper understanding of the key factors affecting the survival of endangered species. Therefore, more data-based learning and scientific references need to be strengthened so that students can have a more accurate understanding of Javan leopard conservation. Table 2 was a follow-up question regarding the knowledge of prospective biology teacher students related to the conservation of the Javan leopard.

Table 2. Prospective Biology Teacher Knowledge about Javan Leopard Conservation in Indonesia

Statements	Yes (%)	No (%)
The Javan leopard is an endangered species	100	0
In the Gunung Sawal Animal Sanctuary, West Java, there is still a Javan leopard	87.3	12.7
The Javan leopard is the peak of predator on Java Island	84.7	15.3
I already know about the conservation efforts of the Javan leopard	70.3	29.7
In Indonesia, leopards do not attack human settlements	66.1	33.9
In Indonesia, leopards are naturally only found on Java Island	54.2	45.8
Javan leopards have been found outside conservation areas	49.2	50.8

Based on Table 2, almost all respondents (100%) were aware that the Javan leopard is endangered. This shows a high level of awareness regarding the threats faced by this species. Belief in Existence in the Wild: Most respondents (87.3%) were confident that the Javan leopard still exists in the Gunung Sawal Wildlife Sanctuary in West Java. This indicates that the Javan leopard population can still be maintained. Understanding of Ecological Role: Most respondents (84.7%) understood that the Javan leopard is the apex predator on Java Island, indicating an understanding of its important role in the ecosystem. Level of Knowledge about Conservation Efforts: Around 70.3% of respondents stated that they were aware of the conservation efforts of the Javan leopard. This shows that there are quite good socialization efforts regarding the conservation of this species. Myths about Attacks on Settlements: There are varying perceptions regarding leopard attacks on human settlements. About 66.1% of respondents believed that leopards did not attack human settlements, but there were still about 33.9% who had the opposite perception. Understanding of Natural Distribution: Most respondents (54.2%) understood that leopards were naturally only found on Java Island. Perception of Existence Outside Conservation Areas: Respondents' opinions were quite evenly divided regarding the possibility of finding Javan leopards outside conservation areas.

Figure 4 illustrates the source of information that prospective biology teacher students know about leopards for the first time. From the data presented, we could see that 54 respondents (45.8%) knew about leopards through television. This shows that television media has a significant role in disseminating information about wildlife, including leopards. Considering the era of prospective biology teachers as children, the internet condition is still limited, so a lot of information comes from television. According to Aitchison et al. (2021), it was difficult to measure the usefulness of various wildlife TV programmes that could reach global audiences. However, based on the responses from the respondents, television can provide essential information for education in identifying endangered species.

The second position was occupied by 32 respondents, with the source of information from teachers in schools (27.1%). This indicates that formal education in schools also makes a considerable contribution to introducing students to the animal world, including leopards. 16 respondents chose book (13.6%), 10 respondents chose video platforms such as YouTube (8.5%), and 1 respondent chose a lecturer (0.8%).

Meanwhile, other sources of information accounted for only 5 (4.2%) of the total respondents, which were posters that usually display various types of animals.

Figure 5 shows the responses from prospective biology teacher students related to their interests in the conservation of the Javan leopard.

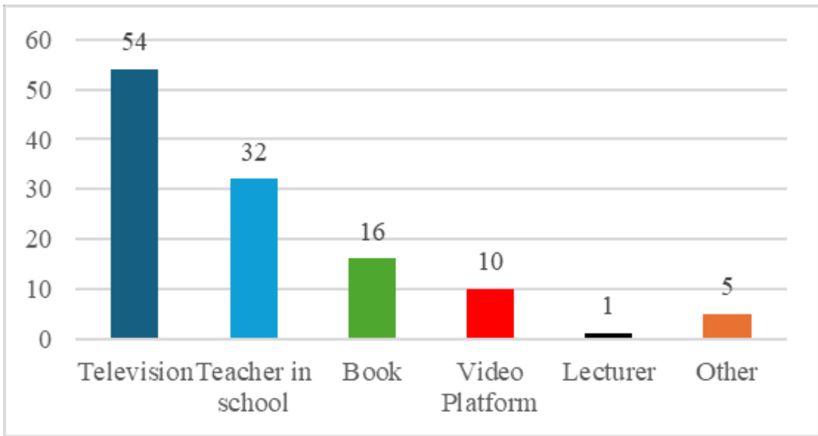
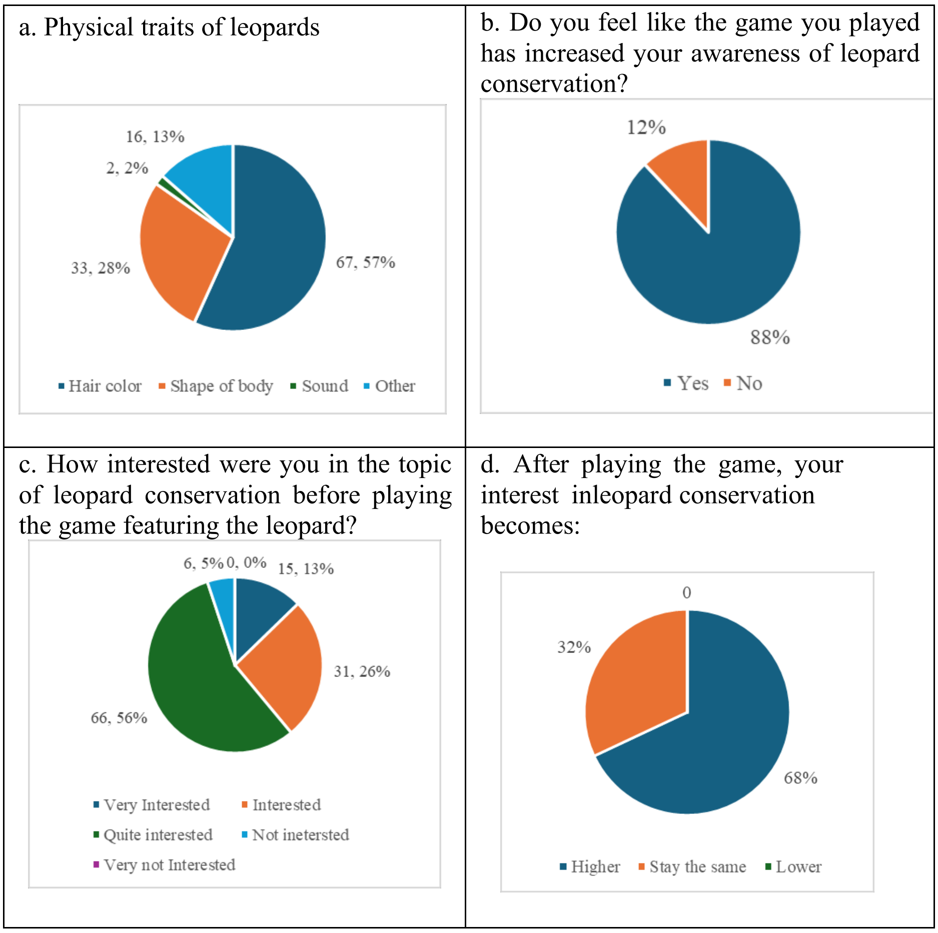


Figure 4. First Time Knew about Leopards



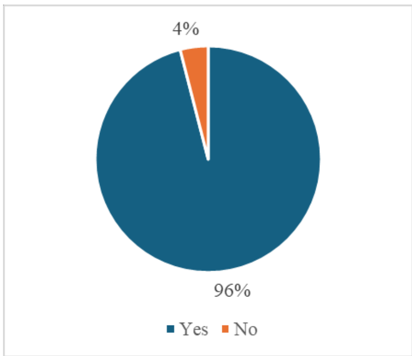
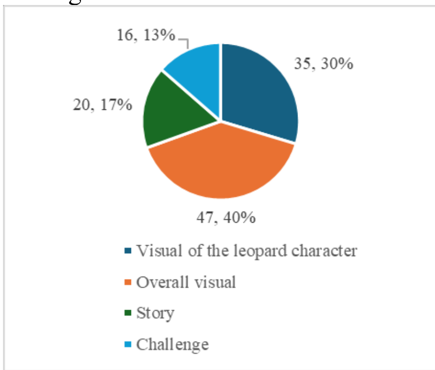
e. Do you want to see more games that raisethe theme of leopard conservation?	f. What elements in the game do you think are most effective in conveying the message of conservation?
	

Figure 5. Prospective Biology Teacher Student' Interests in the Conservation of Javan Leopard

The first graph (a) shows the physical characteristics of leopards that respondents remember the most after playing the game. The results were quite interesting: most respondents remembered the colour of leopard hair (67.57%). This indicates that its distinctive coat colour is the most prominent and memorable physical feature. The second graph (b) shows the effectiveness of the game in raising awareness about leopard conservation. The results were very positive, as most respondents (88%) felt that after playing the game, their awareness regarding the importance of leopard conservation increased because the game managed to convey the message about the importance of animal conservation.

The third graph (c) shows the level of respondents' interests in leopard conservation before they played the game. The results showed that most respondents had a high interest in leopard conservation before playing the game (66.56%), meaning that they generally already had awareness of the importance of preserving wildlife. The fourth graph (d) shows the change in respondents' interest in leopard conservation after they played the game. The results were very positive with most respondents (68%) stating that their interest in leopard conservation increased after playing the game. This shows that the games played are quite effective in raising awareness and concern for wildlife conservation.

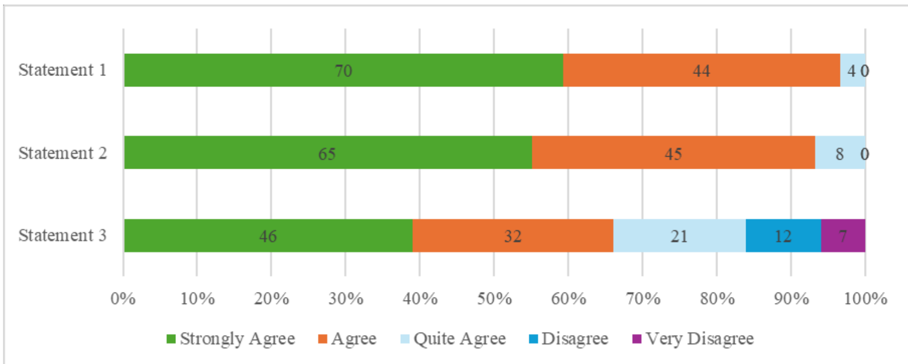


Figure 6. Attitudes of Prospective Biology Teachers towards Javan Leopard Conservation

(Statement 1: If I were a teacher or parent, I would teach students about the importance ofprotecting leopards; Statement 2: Conservation education should be integrated with the curriculum in schools; Statement 3: Leopards and humans can live in harmony)

The figure showed the results of a survey that measured the level of respondents' approval of three statements related to leopard conservation and conservation education. In Statement 1 (the invitation to teach the importance of leopard protection to students), the majority of 70 respondents (59.3%) strongly agreed, followed by 44 (37.3%) who agreed, while only 4 respondents quite agreed (3.4%). For Statement 2 (conservation education should be integrated into the school's curriculum), 65% of respondents strongly agreed, 45% agreed, 8% quite agreed, and none of the respondents disagreed. Statement 3 (humans and leopards can live in harmony) received more varied responses. Only 46% of respondents strongly agreed, 32% agreed, while 21% quite agreed. As many as 12% of respondents disagreed, while 7% very disagreed. From these results, there is strong support for the teaching of leopard conservation and the integration of conservation education in the curriculum, but there is more doubt aboutthe possibility of harmonious living between humans and leopards

Challenges Ahead in The Development of Game-Based Learning to Raise Awareness of Leopard Conservation

Based on this, questions were then made that led to recommendations and expectations for Game-Based Learning related to leopard conservation. Question 1: What features would you like to see in the game about leopard conservation? Question 2: How can the game contribute more to leopard conservation efforts in the real world? Question 3: What kind of games do you think can be more effective in educating the public about leopard conservation? This question can also be the basis for other researchers in the development of GBL for the conservation of endangered species in the future. The questions were analysed using Word Cloud as shown in Figure 7, Figure 8 and Figure 9 as follow.

Figure 7. Word Cloud on Expected Features in the Game

Figure 7 was the result of a Word Cloud that highlighted various keywords related to leopard conservation and aspects that support its protection efforts. The words "leopards" and "conservation" appeared most dominantly, suggesting that the focus was on conservation efforts for the species. Surrounding these words were important concepts such as "habitat", "features," "education," and "ecosystem," which referred to critical aspects of conservation, such as habitat conservation, educational elements, and the importance of ecosystem balance. Words such as "players," "game," and "simulation" denoted a game-based or simulation-based approach to engaging the public in conservation missions, in which players participated in scenarios of habitat management, species protection, and ecosystem restoration. Other concepts, such as "poaching" and "rehabilitation", emphasize challenges and solutions to preserve leopards in the wilderness. Based on the results of Word Cloud, it can also be concluded that some additional features in the game still need to be made, such as the addition of players because multiplayer games are quite a trend, and each student can interact directly in the game.

Figure 8. Word Cloud on the Contribution of Games towards Conservation in the Real World

Based on the Word Cloud in Figure 8, the game could contribute to the conservation of the Javan leopard. Based on the questions raised, most of the respondents' words obtained from the game could play a significant role in raising awareness and understanding of the Javan leopard conservation. The contribution of education through GBL using leopards provides various interesting perspectives. Games can also be given in another way, not only through digital form but also through simple learning, which is role-playing.

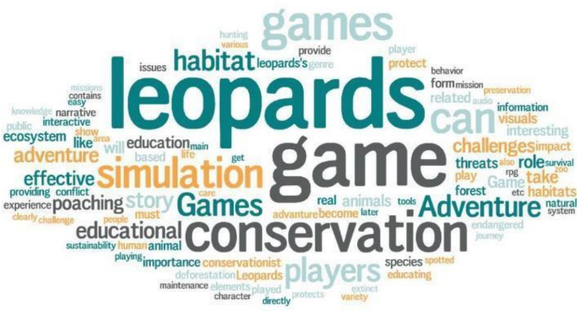


Figure 9. Word Cloud on Effective Types of Games for Conservation Education

Based on the results of the open questionnaire in Figure 9, the types of Javan leopard conservation games were depictions of habitats, simulations, adventures, and challenges. These various game recommendations can certainly contribute to Javan leopard conservation education. It also shows that games can effectively increase public awareness and understanding of the importance of preserving the Javan leopard species. Games have enormous potential to be an effective tool in educating the public about the importance of leopard conservation. By designing games that are engaging, educational, and relevant, we can inspire the younger generation to care about nature conservation and take concrete action to protect endangered species such as the Javan leopard.

Discussion

Game-Based Learning inserts information on the Javan leopard regarding its contribution to biodiversity conservation due to various factors: deforestation, plantations, and infrastructure development. Habitat loss reduces leopards' movement space and the availability of prey and disrupts the balance of the ecosystem (Shanida et al., 2018). The loss of such habitat can also increase conflicts with humans. Games can be a powerful tool to understand and overcome conflicts in conservation (Redpath et al., 2018). Prior knowledge of leopards from the prospective biology teacher can also provide an overview of what is included in their long-term memories when they first knew leopards. This proves that various media such as television, YouTube, books, and social media have increased public awareness of wildlife conservation (Shrader & Louw, 2023; Wu et al., 2018). From here, we must also realise the important role of teachers in schools to introduce the species that exist around their students.

Although the game only provides information about 3D images of leopards that are more oriented towards the community in ecology, it can provide a new insight into GBL that leads to the conservation of rare species. With the game, students can also learn about endangered organisms and the importance of biodiversity for life, as well as apply scientific knowledge and skills to educate the public about conservation (Hacıoğlu & DönmezUsta, 2020). The games should be developed more into other interesting and educational aspects that contribute to biodiversity conservation. This is in line with Tan et al. (2018), stating that if the conservation games were used correctly, they played an important role in making conservation more interesting and in-depth.

Based on the analysis of Word Cloud (Figures 7-9), the ideal leopard conservation game is not only to entertain but also to provide a powerful biodiversity conservation education. In GBL, players should be exposed to realistic ecosystem simulations, allowing them to play an active role in conservation missions that reflect real-world challenges. By including features such as species rescue missions, direct interaction with dynamic environments, and in-depth storylines, the game should also be able to provide an educational and entertaining experience. In addition, it can be developed with additional multiplayer elements, charming visuals, and the integration of scientific knowledge, ensuring that this game is relevant and interesting for players of all ages, including students and the public.

The educational aspect of the game can focus on a deep understanding of ecology, leopard biology, as well as the significant role of biodiversity conservation. Through an interactive approach, players learn about the leopard's natural habitat, its threats (poaching and habitat destruction), and the conservation efforts being undertaken by experts. By engaging players emotionally through immersive simulations, the game also has the potential to develop empathy for wildlife and raise awareness about the importance of maintaining the balance of the ecosystem. Appropriate and interesting game-based game design can be used as a new involvement to improve ecological literacy, an ecological challenge related to biodiversity conservation (Callahan et al., 2019). GBL can serve as an effective educational tool, motivating players to take real action in their daily lives, supporting species conservation, as well as being part of real-world biodiversity conservation efforts.

GBL is recommended as an innovative method in protected wildlife conservation education, as it can provide an interactive, in-depth, and engaging learning experience. Through realistic ecosystem simulations and missions that reflect real conservation challenges, the game can improve players' understanding of the importance of preserving biodiversity. Students' involvement in educational games can affect the effectiveness of learning (Yu et al., 2021). Players are not only invited to understand the biological and ecological aspects of wildlife (such as leopards) but also invited to experience the firsthand impact of threats such as poaching and habitat destruction. This game can serve as an effective educational tool by motivating players to engage in conservation efforts through a fun and interactive approach. If this play-based learning continues to be developed, it could potentially support conservation research for players to collect data or utilise games in identifying solutions to real-world problems (Sandbrook et al., 2015). Thus, GBL has enormous potential in increasing public awareness, especially the younger generation, regarding the importance of protected wildlife conservation and the balance of the ecosystem.

Many studies have shown that GBL enhances students' engagement, motivation, and conceptual understanding of biodiversity and conservation issues. For instance, research by Wijoyo et al. (2025) stated that GBL used in biodiversity conservation learning can significantly increase knowledge. This is in line with the research conducted by Kamaruzaman and Rozuki (2024), which strengthens previous research on GBL in endangered species conservation by showing that interactive and immersive features effectively improve engagement, knowledge retention, and pro-conservation attitudes among learners. However, some studies (Adipat et al., 2021; Behnamnia et al., 2023; Jääskä & Aaltonen, 2022) have reported challenges in the use of GBL, such as limited accessibility, technology constraints (high cost), and physical game constraints that also impact cognitive load and stress. Although there are uncertainties regarding these challenges, this study is expected to provide new insights into GBL. In addition, while the study focuses on rare species such as the Javan leopard in the context of local conservation, it may offer unique findings that are not directly comparable to the broader GBL study.

Because this research is a preliminary study in the development of ecological education games, this research only includes the Javan leopard as one of the elements in the game. There is no analysis of thinking skills for prospective biology teacher students, because it is only a promotional medium for the conservation of the Javan leopard. The statistical analysis used is still simple; there is no way to see the correlation of various existing aspects between knowledge and interest or knowledge and attitude. The GBL that has been developed will be further researched to see how the game affects critical thinking skills.

Conclusion

The study concludes that Game-Based Learning (GBL), which includes information about endangered species like the Javan leopard, has great potential to support biology education and raise awareness about biodiversity conservation. It is recommended as an innovative method for wildlife conservation education because it offers an interactive and engaging learning experience. With the right design and content, games can be both fun and effective for learning, while also promoting efforts to conserve endangered species. The study found that introducing local and threatened species through GBL for prospective biology teachers can improve their knowledge, attitudes, interest, and concern for the conservation of threatened species like the Javan leopard.

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References

Adipat, S., Laksana, K., Busayanon, K., Ausawasowan, A., & Adipat, B. (2021). Engaging Students in the Learning Process with Game-Based Learning: The Fundamental Concepts. International Journal of Technology in Education, 4(3), 542–552. https://doi.org/10.46328/ijte.169

Aitchison, J., Aitchison, R., & Devas, F. (2021). Assessing the environmental impacts of wildlife television programmes. People and Nature, 3(6), 1138–1146. https://doi.org/10.1002/pan3.10251

Alamshoev, Q., Alamshev, C., Akmatova, K., Ayusheev, V. (Norbu), Azhunova, M., Chelteuv, S., Erdenetsogt, B., Garmaev, R., Hillard, D., Ivashkina, L., Khurelbataar, E., Khuukhenduu, T., Osmanova, A., Padmanabhan, S., Raymbekov, Z., Shaidoev, S., & Weddle, M. (2024). Environmental education for snow leopard conservation. In Snow Leopards (pp. 275–285). Elsevier. https://doi.org/10.1016/B978-0-323-85775- 8.00054-6

Almeida, D., Pinheiro, L. B. L. G., Guerrero, J. V. R., Costa, R. T., Trevisan, D. P., Scariot, E. C., Brisbois, J., & Moschini, L. E. (2024). Connecting biogeography, ecology, and history through a game-based learning approach. American Journal of Social Sciences and Humanities, 9(1), 21–37. https://doi.org/10.55284/ajssh.v9i1.1142

Altassan, A. (2023). Sustainable Integration of Solar Energy, Behavior Change, and Recycling Practices in Educational Institutions: A Holistic Framework for Environmental Conservation and Quality Education. Sustainability, 15(20), 15157. https://doi.org/10.3390/su152015157

Ario, A., Mercusiana, S., Rustiadi, A., Gumilang, R., I Gede Gelgel Darma Putra Wirawan, & Ahmad Slamet, T. (2022). The Javan Leopard Panthera pardus melas (Cuvier, 1809) (Mammalia: Carnivora: Felidae) in West Java, Indonesia: estimating population density and occupancy. *Journal of Threatened Taxa, 14*(7),

21331–21346. https://doi.org/10.11609/jott.7483.14.7.21331-21346
Ario, A., Murdyatmaka, W., Gitayana, A., & Hariyanto, G. (2022). First record of rare mating behavior of Javan leopard Panthera pardus melas in Indonesia. *Tropical Zoology, 35*(1–2). https://doi.org/10.4081/tz.2022.120
Ariyanto, A. C., Wang, T., Skidmore, A. K., Wibisono, H. T., Widodo, F. A., Firdaus, A. Y., Wiharisno, Y., Koliq, N., & Murdyatmaka, W. (2024). Range-wide camera traps reveal potential prey species for Javan leopards. Global Ecology and Conservation, 53, e03020. https://doi.org/10.1016/j.gecco.2024.e03020
As'ary, M., Setiawan, Y., & Rinaldi, D. (2023). Analysis of Changes in Habitat Suitability of the Javan Leopard (Panthera pardus melas, Cuvier 1809) on Java Island, 2000–2020. Diversity, 15(4), 529. https://doi.org/10.3390/d15040529
Barthwal, S. C., & Mathur, V. B. (2012). Teachers' Knowledge of and Attitude Toward Wildlife and Conservation. Mountain Research and Development, 32(2), 169. https://doi.org/10.1659/MRD-JOURNAL-D-11-00040.1
Behnamnia, N., Kamsin, A., Ismail, M. A. B., & Hayati, S. A. (2023). A review of using digital game-based learning for preschoolers. Journal of Computers in Education, 10(4), 603–636. https://doi.org/10.1007/s40692-022-00240-0
Børresen, S. T., Ulimboka, R., Nyahongo, J., Ranke, P. S., Skjaervø, G. R., & Røskaft, E. (2023). The role of education in biodiversity conservation: Can knowledge and understanding alter locals' views and attitudes towards ecosystem services? EnvironmentalEducationResearch,29(1),148163.https://doi.org/10.1080/13504622.2022.2117796
Callahan, M. M., Echeverri, A., Ng, D., Zhao, J., & Satterfield, T. (2019). Using the Phylo Card Game to advance biodiversity conservation in an era of Pokémon. Palgrave Communications, 5(1), 79. https://doi.org/10.1057/s41599-019-0287-9
Cosme, L., Turchen, L. M., & Guedes, R. N. C. (2020). Insect World: Game-Based Learning as a Strategy for Teaching Entomology. The American Biology Teacher, 82(4), 210– 215. https://doi.org/10.1525/abt.2020.82.4.210
Dewanti, A. A., & Marhaento, H. (2021). Perception Analysis on the Conflict Between Javan Leopard and Community Around Mount Sawal Wildlife Reserve. Jurnal Penelitian Sosial Dan Ekonomi Kehutanan, 18(2), 75–85.
Dhungana, R., Maraseni, T., Silwal, T., Aryal, K., & Karki, J. B. (2022). What determines attitude of local people towards tiger and leopard in Nepal? Journal for Nature Conservation, 68, 126223. https://doi.org/10.1016/j.jnc.2022.126223
Gerl, T., Randler, C., & Jana Neuhaus, B. (2021). Vertebrate species knowledge: an important skill is threatened by extinction. International Journal of Science Education, 43(6), 928– 948. https://doi.org/10.1080/09500693.2021.1892232
Gomez, L., & Shepherd, C. R. (2021). The illegal exploitation of the Javan Leopard (Pantherapardus melas) and Sunda Clouded Leopard (Neofelis diardi) in Indonesia. Nature Conservation, 43, 25–39. https://doi.org/10.3897/natureconservation.43.59399
Goodale, A. Y., Gilmore, M. P., & Griffiths, B. M. (2025). 21st-century stewardship: infusing environmental stewardship education with global

citizenship. Environmental Education Research, 31(2), 364–389. https://doi.org/10.1080/13504622.2024.2335614
Gunawan, H., Iskandar, S., Sihombing, Vivin S., & Wienanto, R. (2017). Conflict between humans and leopards (Panthera pardus melas Cuvier, 1809) in Western Java, Indonesia. Biodiversitas Journal of Biological Diversity, 18(2), 652–658. https://doi.org/10.13057/biodiv/d180229
Hacıoğlu, Y., & Dönmez Usta, N. (2020). Digital game design-based STEM activity: Biodiversity example. Science Activities, 57(1), 1–15. https://doi.org/10.1080/00368121.2020.1764468
Jääskä, E., & Aaltonen, K. (2022). Teachers' experiences of using game-based learning methods in project management higher education. Project Leadership and Society, 3, 100041. https://doi.org/10.1016/j.plas.2022.100041
Jones, S. M., Katyal, P., Xie, X., Nicolas, M. P., Leung, E. M., Noland, D. M., & Montclare,
J. K. (2019). A 'KAHOOT!' Approach: The Effectiveness of Game-Based Learning for an Advanced Placement Biology Class. Simulation & Gaming, 50(6), 832–847. https://doi.org/10.1177/1046878119882048
Kamaruzaman, N. N. N., & Rozuki, N. A. H. (2024). An Educational Wildlife Game-based Learning Application for Young Learners Using Augmented Reality. Applied Mathematics and Computational Intelligence (AMCI), 13(4), 33–48. https://doi.org/10.58915/amci.v13i4.1475
Kementrian Lingkungan Hidup dan Kehutanan. (2024). Indonesian Biodiversity Strategy and Action Plans 2025-2045. Kementrian Lingkungan Hidup dan Kehutanan.
Meekaew, N., & Ketpichainarong, W. (2018). An Augmented Reality to Support Mobile Game-Based Learning in Science Museum on Biodiversity. 2018 7th International Congress on Advanced Applied Informatics (IIAI-AAI), 250–255. https://doi.org/10.1109/IIAI-AAI.2018.00055
Miralles, L., Garcia-Vazquez, E., & Dopico, E. (2021). Game-based learning for engaging citizens in biopollution control. Interdisciplinary Science Reviews, 46(4), 677–688. https://doi.org/10.1080/03080188.2021.1891684
Moheb, Z., Fuller, T. K., & Zahler, P. I. (2022). Snow leopard - human conflict as aconservation challenge - a review. Snow Leopard Reports, 1. https://doi.org/10.56510/slr.v1.8158
Palmberg, I., Hermans, M., Jeronen, E., Kärkkäinen, S., Persson, C., & Yli-Panula, E. (2018). Nordic Student Teachers' Views on the Importance of Species and Species Identification. Journal of Science Teacher Education, 29(5), 397–419. https://doi.org/10.1080/1046560X.2018.1468167
Partasasmita, R., Shanida, S. S., Iskandar, J., Megantara, E. N., Husodo, T., & Malone, N. (2016). Human-Leopard Conflict in Girimukti Village, Sukabumi, Indonesia.
Qaffas, A. (2020). An Operational Study of Video Games' Genres. International Journal of Interactive Mobile Technologies (IJIM), 14, 175. https://doi.org/10.3991/ijim.v14i15.16691
Qian, M., & Clark, K. R. (2016). Game-based Learning and 21st century skills: A review of recent research. Computers in Human Behavior, 63, 50–58. https://doi.org/10.1016/j.chb.2016.05.023
Ramadiani, R., Respatti, E., Putra, G. M.,

Jundillah, M. L., Rahman, T., Balfas, M. D., Yunianta, A., & Alyamani, H. J. (2021). The Development of Borneo Wildlife Game Platform. International Journal of Advanced Computer Science and Applications, 12(10). https://doi.org/10.14569/IJACSA.2021.0121061

Rani, M., Singh, S. K., Allen, M. L., Pandey, P., & Singh, R. (2024). Measuring people's attitude towards conservation of Leopard Panthera pardus (Mammalia: Carnivora) in the foothills of Himalayan region. Journal of Threatened Taxa, 16(6), 25283–25298. https://doi.org/10.11609/jott.8567.16.6.25283-25298

Redpath, S. M., Keane, A., Andrén, H., Baynham-Herd, Z., Bunnefeld, N., Duthie, A. B., Frank, J., Garcia, C. A., Månsson, J., Nilsson, L., Pollard, C. R. J., Rakotonarivo, O. S.,Salk, C. F., & Travers, H. (2018). Games as Tools to Address Conservation Conflicts. Trends in Ecology] & Evolution, 3(6), 415–426. https://doi.org/10.1016/j.tree.2018.03.005

Robinson, N. M., Scheele, B. C., Legge, S., Southwell, D. M., Carter, O., Lintermans, M., Radford, J. Q., Skroblin, A., Dickman, C. R., Koleck, J., Wayne, A. F., Kanowski, J., Gillespie, G. R., & Lindenmayer, D. B. (2018). How to ensure threatened species monitoring leads to threatened species conservation. Ecological Management & Restoration, 19(3), 222–229. https://doi.org/10.1111/emr.12335

Sandbrook, C., Adams, W. M., & Monteferri, B. (2015). Digital Games and Biodiversity Conservation. Conservation Letters, 8(2), 118–124. https://doi.org/10.1111/conl.12113

Sanzana, M. R., Abdulrazic, M. O. M., Wong, J. Y., Karunagharan, J. K., & Chia, J. (2024).Gamified virtual labs: shifting from physical environments for low-risk interactive learning. Journal of Applied Research in Higher Education, 16(1), 208–221. https://doi.org/10.1108/JARHE-09-2022-0281

Shanida, S. S., Partasasmita, R., Husodo, T., Parkesit, P., Febrianto, P., & Megantara, E. N. (2018). Short Communication: The existence of Javan Leopard (Panthera pardus melas Cuvier, 1809) in the non-conservation forest areas of Cisokan, Cianjur, West Java, Indonesia. Biodiversitas Journal of Biological Diversity, 19(1), 42–46. https://doi.org/10.13057/biodiv/d190107

Shrader, A. M., & Louw, I. (2023). Using a social media project as a way to get students to communicate conservation messages to the general public. Journal of Biological Education, 57(3), 484–494. https://doi.org/10.1080/00219266.2021.1924231

Situmorang, R. P., Suwono, H., Munzil, M., Susanto, H., Chang, C.-Y., & Liu, S.-Y. (2024). Learn biology using digital game-based learning: A systematic literature review. Eurasia Journal of Mathematics, Science and Technology Education, 20(6), em2459. https://doi.org/10.29333/ejmste/14658

Skarstein, T. H., & Skarstein, F. (2020). Curious children and knowledgeable adults – early childhood student-teachers' species identification skills and their views on the importance of species knowledge. International Journal of Science Education, 42(2), 310–328. https://doi.org/10.1080/09500693.2019.1710782

Suprapto, P. K., Suharsono, Chaidir, D. M., & Ali, M. (2019). Development of Wimba 3 Dimension Interactive Animation Media on Plant Anatomy.

Journal of Physics: Conference Series, 1233, 012002. https://doi.org/10.1088/1742-6596/1233/1/012002
Tan, C. K. W., Woei Lee, J., Hii, A., Loo, Y. Y., Campos-Arceiz, A., & Macdonald, D. W. (2018). The effect of using games in teaching conservation. PeerJ, 6, e4509. https://doi.org/10.7717/peerj.4509
Uduman, A., Hagerman, S., Kroc, E., Watson, A., Kittle, A., & Burton, A. C. (2022). Attitudes towards the Sri Lankan leopard Panthera pardus kotiya in two rural communities. Oryx, 56(4), 528–536. https://doi.org/10.1017/S0030605321000247
Wibisono, H. T., Wahyudi, H. A., Wilianto, E., Pinondang, I. M. R., Primajati, M., Liswanto, D., & Linkie, M. (2018). Identifying priority conservation landscapes and actions for the Critically Endangered Javan leopard in Indonesia: Conserving the last large carnivore in Java Island. PLOS ONE, 13(6), e0198369. https://doi.org/10.1371/journal.pone.0198369
Wijoyo, S., Ahman, E., Kurniawati, S., Supardi, E., & Firdaus, M. M. (2025). The Use of Board Games in Teaching Biodiversity for Sustainable Development: A Quasi-Experimental Method. International Journal of STEM Education for Sustainability, 5(1), 53-71.
Wright, D. S., Crooks, K. R., Hunter, D. O., Krumm, C. E., & Balgopal, M. M. (2021). Middle school science teachers' agency to implement place-based education curricula about local wildlife. Environmental Education Research, 27(10), 1519–1537. https://doi.org/10.1080/13504622.2021.1960955
Wu, Y., Xie, L., Huang, S.-L., Li, P., Yuan, Z., & Liu, W. (2018). Using social media to strengthen public awareness of wildlife conservation. Ocean & Coastal Management, 153, 76–83. https://doi.org/10.1016/j.ocecoaman.2017.12.010
Yadav, S. K., Banerjee, A., Jhariya, M. K., Meena, R. S., Raj, A., Khan, N., Kumar, S., & Sheoran, S. (2022). Environmental education for sustainable development. In Natural Resources Conservation and Advances for Sustainability (pp. 415–431). Elsevier. https://doi.org/10.1016/B978-0-12-822976-7.00010-7
Yuliawan, K., Prayitno, G., Wijono, S., Joko Prasetyo, S. Y., & Trihandaru, S. (2022). Android-Based Educational Game: Recognition of Papua Endemic Animals. Jurnal Teknik Informatika (Jutif), 3(4), 889–896. https://doi.org/10.20884/1.jutif.2022.3.4.319
Yu, Z., Gao, M., & Wang, L. (2021). The Effect of Educational Games on Learning Outcomes, Student Motivation, Engagement and Satisfaction. Journal of Educational Computing Research, 59(3), 522–546. https://doi.org/10.1177/0735633120969692

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Relevance of Science Education for Self-reliance and National Economic Development

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Abstract

This study investigates the role of science education as a catalyst for economic development and self-reliance by drawing on case studies from developed countries and synthesising key themes from a systematic literature review. Using qualitative content analysis of 15 selected studies, the review reveals that integrating rigorous theoretical instruction with practical, hands-on training, as exemplified by Germany's dual education system, South Korea's integrated science and technology approach, the innovation-driven environment in the United States, and Israel's agri-tech successes, can enhance workforce readiness, drive technological innovation, and stimulate entrepreneurial activity. These international examples provide valuable insights for Nigeria, suggesting that similar strategies could improve local economic competitiveness and reduce dependency on foreign expertise. However, the study also identifies significant challenges, including inadequate funding, outdated curricula, and insufficient infrastructural support, which hinder the full realisation of science education's potential. The findings underscore the need for targeted educational reforms and strategic investments to translate these benefits into sustainable economic growth and development.

Keywords: Economic Development; Entrepreneurship; Self-reliance; Science Education; Sustainable Economic Growth

Introduction

Science education, which is characterised by the organised teaching and learning of scientific disciplines, aims to cultivate a thorough comprehension of essential scientific concepts and promote critical thinking and analytical abilities. Science education is essential for establishing a basis for technological innovation, economic development, and societal improvement. In developing economies, especially in countries like Nigeria, science education plays a crucial role in promoting self-reliance, which is essential for minimising dependence on foreign expertise and resources (Okafor, 2018; Olofin et al., 2023). At the heart of economic development, self-reliance signifies a nation's capability to effectively harness its human and natural resources to achieve sustainable growth and enhance the quality of life for its citizens (Ankeli, 2019; Shamsuddin et al., 2018).

Science education is increasingly recognised as a vital instrument for driving economic growth by fostering innovation and creativity among students, thereby developing a skilled workforce proficient in problem-solving (Mbanefo & Eboka, 2017). It functions as more than just an academic pursuit, offering a practical means to improve scientific literacy and technical expertise. Global trends reveal that countries that prioritise science education often achieve rapid technological advancements and economic expansion. Research by Umar (2019) and Adolphus (2020) highlights that science education is crucial in supporting key economic sectors, including agriculture, information technology, and manufacturing, indicating that it not only benefits individuals but also significantly boosts national economic performance through enhanced productivity and economic activity (Musa et al., 2016).

Science education has been recognised as a cornerstone for economic advancement and national self-reliance in many advanced countries. In these countries, robust science education systems have not only produced highly skilled workforces but also driven technological innovation and industrial growth. For instance, Germany's dual education model successfully integrates classroom learning with on-the-job training (Baethge & Wolter, 2015; Solga et al., 2014), while South Korea's strong focus on science and technology education has catalysed significant advancements in healthcare and technology (Kim, 2017; Lee et al., 2020). Similarly, China has leveraged extensive investments in science education to become a global leader in technological innovation and economic expansion (Fu & Zhang, 2011; Li, 2017; Williamson & Yin, 2014). Japan's emphasis on Science, Technology, Engineering and Mathematics (STEM) disciplines has maintained its competitive edge in high-tech manufacturing and innovation (Urbanova, 2018), and India's growing focus on science education has contributed to the emergence of its dynamic IT and pharmaceutical sectors (Guennif & Ramani, 2011; Jakovljevic et al., 2021; Sen et al., 2011). Furthermore, the United States continues to be a global leader in research and development, driven by a robust science education system that fosters critical thinking and creativity (Kutty et al., 2020; Lee & Haupt, 2019).

However, the full potential of science education in Nigeria has not yet been completely harnessed. Challenges such as inadequate funding, outdated curricula, and a misalignment between educational outcomes and labour market demands have hindered progress (Adeoye et al., 2023). There is often a significant gap between the expected competencies outlined in educational policies and the actual skills acquired by students. Innovations in curricula and teaching methodologies, focused on practical applications of scientific theory, are critical in enhancing the effectiveness of science education (Olofin et al., 2023). A well-structured education system aligned with the socio-economic goals of the country can play a transformative role in national development.

Self-reliance, in the context of national development, means enabling individuals to engage actively in economic activities without excessive reliance on external assistance (Shamsuddin et al., 2018). It is a multidimensional concept that includes achieving economic independence, optimising resources, and promoting innovation and entrepreneurship. For emerging economies like Nigeria, self-reliance is vital for lowering unemployment and improving competitiveness in the global arena (Ankeli, 2019). The interplay between self-reliance and science education is mutually reinforcing. By nurturing the entrepreneurial skills and competencies necessary for industrial and economic innovation, science education lays the groundwork for self-reliance (Okafor, 2018). Focused educational initiatives empower students with the capabilities to undertake projects that boost self-sufficiency, create job opportunities, and drive widespread economic development.

Moreover, incorporating entrepreneurship into science education fosters an entrepreneurial mindset, enabling individuals to utilise local resources and address community-specific challenges. Programmes that merge entrepreneurship with science education have yielded positive results by strengthening innovation-driven enterprises and advancing industrial development (Shamsuddin et al., 2018; Obori, 2012). Thus, promoting self-reliance through science education is critical for enhancing national resilience and ensuring long-term economic stability.

Economic development is the process of improving the overall well-being of a nation's populace economically, politically, and socially, through various initiatives that increase productivity, efficiency, and economic diversification (Umar, 2019). Science education is central to this process as it provides the skilled workforce necessary for productive economic activities and underpins technological advancements that drive development. Numerous empirical studies consistently demonstrate a strong link between science education and key economic indicators, including Gross Domestic Product (GDP) growth, industrial output, and employment rates (Olofin et al., 2023; Adolphus, 2020). In Nigeria, where the youth demographic is substantial, science education plays a particularly significant role in spurring economic development. By investing in education systems that focus on STEM disciplines, Nigeria can leverage its demographic advantage to build a more dynamic and competitive economy (Aniashi et al., 2019; Mbanefo & Eboka, 2017).

Despite its potential, the contribution of science education to economic development in Nigeria is constrained by systemic challenges such as insufficient funding, inadequate infrastructure, and policy implementation gaps (Enemuo & Ozoemena, 2020). Addressing these obstacles necessitates a holistic approach, where government, industry, and educational institutions collaborate to reform curricula, enhance educational resources, and prioritise science education within national development strategies (Onyebuchi et al., 2024). This paper explores the link between science education, self-reliance, and national economic development, drawing on international experiences and local studies to argue that a strategically reformed science education system can provide Nigerian citizens with the essential skills for innovation and entrepreneurship. The analysis further outlines strategies for aligning educational outcomes with market demands and identifies the challenges that must be overcome to fully harness the benefits of science education in Nigeria.

Methodology

This study employed a Systematic Literature Review (SLR) combined with secondary data analysis to explore the relationship between science education, self-reliance, and national economic development in Nigeria. The SLR approach involves a rigorous process of identifying, selecting, and critically evaluating relevant academic papers, reports, and empirical studies that focus on the Nigerian context or provide pertinent insights into the role of science education in economic development. The literature search was conducted using academic databases such as Google Scholar, JSTOR, PubMed, and relevant educational and economic journals. Key search terms included "science education in Nigeria," "self-reliance," "economic development," "STEM education," and "entrepreneurship." The inclusion criteria were based on the relevance of the studies to the Nigerian context, publication within the last 10 years, and the provision of empirical data or theoretical insights related to science education and economic outcomes. The initial search yielded a large pool of studies, which were then screened for relevance based on titles and abstracts. Studies that did not directly address the Nigerian context or the role of science education in economic development were excluded.

The remaining studies underwent full-text review to assess their methodological rigour, relevance, and contributions to the research questions. In total, 15 studies were selected for in-depth analysis. The selected studies were analysed using qualitative content analysis to identify recurring themes, patterns, and insights related to the impact of science education on economic development and self-reliance. The analysis focused on understanding how science education contributes to four key aspects: skill development, innovation, entrepreneurship, and economic growth. To provide greater clarity, specific indicators were identified for each aspect. For skill development, indicators such as critical thinking assessments and vocational training outcomes were selected to reflect the immediate capacity of graduates to engage in problem-solving and technical tasks. For innovation, the number of patents filed and the level of research and development expenditure were considered, as these indicators demonstrate a nation's ability to generate novel solutions and products. For entrepreneurship, start-up rates and business incubator performance were chosen because they illustrate the dynamism of the entrepreneurial ecosystem and the capacity to translate ideas into viable business ventures. Finally, for economic growth, indicators such as sector-specific contributions to GDP and employment generation rates were used, directly capturing the economic impact of science education initiatives. The selection of these indicators is based on their ability to capture both the individual capabilities developed through science education and their broader economic outcomes.

Finally, the study examined the challenges hindering the effective implementation of science education in Nigeria, such as infrastructural deficiencies, policy gaps, and resource limitations, and how these challenges may impact the effectiveness of the aforementioned indicators. To ensure the robustness of the findings, data triangulation was employed by cross-referencing insights from multiple sources, including government reports and academic papers, including research articles, review papers, and empirical studies. This approach allowed for a comprehensive understanding of the current state of science education in Nigeria and its potential for driving economic development.

Ethical Considerations

Given that this study primarily involves the analysis of secondary data, there were no direct ethical concerns related to human subjects. However, in reviewing the literature, care was taken to ensure that all sources were properly cited and that the intellectual property of original authors was respected. The selection of studies was done transparently, with a focus on minimising bias and ensuring a fair representation of various viewpoints within the existing body of research.

Results and Discussion

Result of Findings

The findings from the qualitative content analysis were synthesised to draw connections between the themes identified in the literature and the broader economic context of Nigeria. This process involved categorising the impacts of science education into distinct areas, namely, skill development, innovation and technological advancement, entrepreneurship, economic contribution (GDP) & employment generation, self-reliance, and policy/infrastructure challenges, as summarised in Table 1. These categories were chosen based on their prominence in existing literature as key dimensions through which science education contributes to national economic development. For instance, the skill development aspect, which is captured by indicators such as critical thinking assessments and vocational training outcomes, demonstrates that science education enhances problem-solving abilities and technical competence. This finding is supported by studies such as Chinyere and Ndirika (2020), Mbanefo and Eboka (2017), and Okafor (2018).

Similarly, the innovation and technological advancement dimension is reflected by the number of patents and research and development expenditure. These indicators suggest that robust science education fosters the development of new technologies and increases overall productivity, as evidenced by research from Adolphus (2020), Kutty et al. (2020), and Olofin et al. (2023). The entrepreneurship category, measured through start-up rates and business incubator performance, indicates that science education plays a significant role in nurturing entrepreneurial initiatives and creating job opportunities (Ankeli, 2019; Obori, 2012; Shamsuddin et al., 2018).

In terms of economic contribution and employment generation, indicators such as sector-specific contributions to GDP and employment rates highlight that science-driven sectors are key to boosting the national economy, as reported by Aniashi et al. (2019), Nwafor and Okoi (2018), and Umar (2019). Additionally, the concept of self-reliance is reinforced by findings that demonstrate how science education supports economic independence by equipping individuals with the skills to develop local solutions, as shown by Shamsuddin et al. (2018) and Ankeli (2019).

Finally, the analysis also reveals policy and infrastructure challenges using indicators such as funding adequacy, curriculum relevance, and infrastructural support, which identify critical systemic gaps that hinder the effective implementation of science education (Adeoye et al., 2023; Enemuo & Ozoemena, 2020; Onyebuchi et al., 2024). The summary of the findings is presented in Table 1 below:

Table 1. Summary of Key Findings on the Role of Science Education in Promoting Self-Reliance and Economic Development in Nigeria

S/N	Theme	Indicators	Key Findings	References
1.	Skill Development and Workforce Readiness	Critical thinking assessments and vocational training outcomes	Science education enhances both analytical (academic) and practical/technical skills, enabling graduates to address real-world challenges in sectors such as manufacturing, technology, healthcare, and agriculture.	Chinyere & Ndirika (2020); Mbanefo & Eboka (2017); Okafor (2018)
2.	Innovation and Technological Advancement	Patent counts, research and development expenditure	Science education stimulates the creation of new technologies and innovative solutions that boost industrial productivity and economic growth.	Adolphus (2020); Kutty et al. (2020); Olofin et al. (2023)
3.	Entrepreneurship	Start-up rates and business incubator performance	Science education fosters entrepreneurial initiatives and job creation, facilitating economic diversification through the practical application of science education.	Ankeli (2019); Obori (2012); Shamsuddin et al. (2018)
4.	Economic Contribution (GDP) & Employment Generation	Sector-specific GDP contributions and employment rates	Science education drives national economic output and diversified employment while promoting self-reliance by reducing dependency on	Aniashi et al. (2019); Nwafor & Okoi (2018); Umar (2019)

			imported technologies and foreign expertise.	
5.	Policy & Infrastructure Challenges / Educational Reform Needs	Funding adequacy, curriculum relevance, and infrastructural support	Identifies systemic barriers that hinder the effective implementation of science education, underscoring the need for comprehensive reforms and targeted investments.	Adeoye et al. (2023); Enemuo & Ozoemena (2020); Onyebuchi et al. (2024)

Discussion of Findings

The findings from this study highlight the critical role that science education plays in fostering economic development and national self-reliance in Nigeria. Science education is not only a means of acquiring academic knowledge but also a powerful driver of practical skills, innovation, and economic progress. The following themes, as reflected in Table 1, are discussed in detail below:

Skill Development and Workforce Readiness

The study finds that science education is crucial in developing a skilled workforce capable of meeting the demands of Nigeria's growing economy. Science education develops both academic (analytical) skills, such as critical thinking and theoretical understanding, and practical or technical skills, which include hands-on training and vocational competencies (Chinyere & Ndirika, 2020; Mbanefo & Eboka, 2017; Okafor, 2018). For example, in manufacturing, students trained through practical apprenticeships (similar to Germany's dual education system) are better equipped to operate complex machinery and improve production processes (Baethge & Wolter, 2015). In technology, practical training in coding and hardware maintenance directly supports innovation and the creation of tech startups (Kutty et al., 2020). In healthcare, hands-on laboratory work complements academic study, leading to breakthroughs in medical research as observed in South Korea (Kim, 2017; Lee et al., 2020). In agriculture, practical modules on modern farming techniques enable graduates to implement sustainable practices, echoing the successes seen in Israel's agri-tech innovations (Urbanova, 2018). These real-world examples underscore how the balanced development of analytical and practical skills through science education enhances workforce readiness and supports self-reliance by enabling individuals to apply their knowledge to solve local challenges.

Innovation and Technological Advancement

The findings indicate that a robust science education system is closely linked to technological innovation. Indicators such as patent counts and research and development expenditure demonstrate that graduates who receive both theoretical instruction and practical training are more likely to engage in research and development activities. For instance, in countries with strong science education systems like the United States, the blend of academic rigour with hands-on innovation has led to a thriving tech startup ecosystem (Kutty et al., 2020; Lee & Haupt, 2019). However, in Nigeria, gaps such as insufficient funding for R&D, limited access to advanced equipment, and weak collaboration between academia and industry hinder innovation. Addressing these gaps through targeted reforms can enhance Nigeria's capacity for technological advancement, enabling the development of indigenous solutions that drive economic growth and self-reliance.

Entrepreneurship

Science education fosters entrepreneurial skills that are crucial for job creation and economic diversification. By providing practical training and nurturing problem-solving abilities, science education empowers graduates to develop and launch innovative business ventures. For example, in sectors like biotechnology and renewable energy, hands-on training equips graduates with the skills needed to convert ideas into viable start-ups (Ankeli, 2019). Similarly, programmes that support business incubators offer the necessary environment for entrepreneurship to flourish, creating new employment opportunities and reducing reliance on traditional industries (Obori, 2012; Shamsuddin et al., 2018). These entrepreneurial activities are essential for diversifying the economy and building a resilient national industry.

Economic Diversification and Employment Generation

Science education significantly contributes to employment generation and economic diversification by equipping graduates with the skills needed in various sectors beyond the traditional oil and gas industry. For example, in renewable energy and biotechnology, practical training enables graduates to innovate and launch start-ups that create new jobs and reduce the country's reliance on fossil fuels. This diversification is essential for building a resilient economy. However, the study finds that misalignment between educational outcomes and labour market demands often leads to unemployment among science graduates. Improving the curriculum to better integrate practical training with academic learning can address this misalignment, ensuring that graduates are capable of contributing effectively to sectors such as manufacturing, technology, healthcare, and agriculture (Chinyere & Ndirika, 2020; Onyebuchi et al., 2024).

Contribution to Gross Domestic Product (GDP)

The analysis reveals that science education indirectly boosts Nigeria's GDP by supporting high-value sectors. Graduates from science education programmes drive productivity and innovation in key sectors. For example, in healthcare, improved research capabilities lead to better medical technologies, and in agriculture, modern farming techniques increase crop yields. These contributions, measured through sector-specific GDP and employment rates, underscore the role of science education in promoting economic self-reliance. However, to fully capitalise on this potential, strategic investments in educational infrastructure and curriculum enhancements are necessary (Nwafor & Okoi, 2018).

Self-Reliance and National Development

The findings reveal that science education is fundamental to achieving national self-reliance. By equipping individuals with both analytical and practical skills, science education enables the development of local solutions tailored to Nigeria's unique challenges, such as improving agricultural productivity through modern techniques or advancing healthcare through indigenous research initiatives. This reduces the country's reliance on foreign expertise and imports, fostering economic independence (Ankeli, 2019). For instance, countries like South Korea and Israel have demonstrated that investment in science education can lead to breakthroughs that not only improve domestic capacities but also position them as global leaders in specific sectors (Kim, 2017; Urbanova, 2018). Thus, for Nigeria, strengthening science education across all levels from primary to tertiary, coupled with supportive policies and adequate funding, is essential for sustainable development and long-term economic stability.

Policy and Infrastructure Challenges / Educational Reform Needs

Systemic challenges hinder the full realisation of science education's potential in Nigeria. Despite the evident benefits, the effective implementation of science education is constrained by inadequate funding, outdated curricula, and insufficient infrastructural support. Studies have identified these policy and infrastructure gaps as critical barriers that prevent the optimal translation of academic and practical skills into economic outcomes (Adeoye et al., 2023; Enemuo & Ozoemena, 2002; Onyebuchi et al., 2024). Addressing these challenges through comprehensive educational reforms and targeted investments is essential to create an enabling environment where science education can fully contribute to national development.

Conclusion

This study investigates the role of science education in fostering economic development and self-reliance. Through a systematic literature review, the study draws on case studies from developed countries and analyses of key themes from the literature. The review shows that combining rigorous theoretical instruction with practical, hands-on training, as demonstrated by Germany's dual education system, South Korea's integrated approach, the innovation-driven environment in the United States, and Israel's success in agri-tech, can enhance workforce readiness, drive technological innovation, and stimulate entrepreneurial activities. These practices offer valuable lessons for Nigeria, suggesting that similar strategies could reduce dependency on foreign expertise and strengthen local economic competitiveness. However, the study also reveals that challenges such as inadequate funding, outdated curricula, and insufficient infrastructure must be addressed. Targeted educational reforms and strategic investments are essential to fully realise the potential of science education as a catalyst for sustainable economic growth and development.

References

Adeoye, M. A., Mahmud, M. A., Ehindero, R. E., Ajape, R. O., Yahaya, A. K., & Jolaoye, J. D. (2023). From flawed to Flourishing: Reshaping the Nigerian curriculum for sustainable national development. *Journal of Education Action Research*, *7*(4), 621–627. https://doi.org/10.23887/jear.v7i4.67812

Adolphus, T. (2020). The role of science education in skills acquisition and youth empowerment in Nigeria. *International Journal of Research Publications, 65*(1), 9-18. https://doi.org/10.47119/ijrp1006511120201546

Aniashi, O., Okaba, A., Anake, U., & Akomaye, U. (2019). Classroom science with everyday life: A means for improving performance in sciences and national development in Nigeria. *International Journal of Science and Technology Educational Research*, *10*(3), 25–29. https://doi.org/10.5897/ijster2019.0457

Ankeli, G. O. (2019). Acquisition of Entrepreneurial and Scientific Skills for Youth Self-Sustainability and Job Creation towards National Development in Nigeria. *World Journal of Entrepreneurial Development Studies, 3*(1), 24-31.

Baethge, M., & Wolter, A. (2015). The German skill formation model in transition: from dual system of VET to higher education? *Journal for Labour Market Research*, *48*(2), 97–112. https://doi.org/10.1007/s12651-015-0181-x

Chinyere, A. P., & Ndirika, M. C. (2020). Promoting Innovation, creativity and entrepreneurship Skills in science Education Students: A Panacea for Employability. *Journal of Education and Practice*, *4*(3), 44–55. https://doi.org/10.47941/jep.477

Enemuo, N. K., & Ozoemena, L. E. (2020). Repositioning of secondary education for economic empowerment through innovation, creativity and entrepreneurship skills in Nigeria. *International Journal of Studies in*

Education, 16(2), 175-186. Retrieved from https://ijose.unn.edu.ng/wp-content/uploads/sites/224/2020/07/pp-175-186-Vol.16-No.-2.pdf

Fu, X., & Zhang, J. (2011). Technology transfer, indigenous innovation and leapfrogging in green technology: the solar-PV industry in China and India. *Journal of Chinese Economic and Business Studies*, *9*(4), 329–347. https://doi.org/10.1080/14765284.2011.618590

Guennif, S., & Ramani, S. V. (2011). Explaining divergence in catching-up in pharma between India and Brazil using the NSI framework. *Research Policy*, *41*(2), 430–441. https://doi.org/10.1016/j.respol.2011.09.005

Jakovljevic, M., Liu, Y., Cerda, A., Simonyan, M., Correia, T., Mariita, R. M., Kumara, A. S., Garcia, L., Krstic, K., Osabohien, R., Toan, T. K., Adhikari, C., Chuc, N. T. K., Khatri, R. B., Chattu, V. K., Wang, L., Wijeratne, T., Kouassi, E., Khan, H. N., & Varjacic, M. (2021). The Global South political economy of health financing and spending landscape – history and presence. *Journal of Medical Economics*, *24*(sup1), 25–33. https://doi.org/10.1080/13696998.2021.2007691

Kim, E. (2017). Sociotechnical imaginaries and the globalization of converging Technology Policy: Technological Developmentalism in South Korea. *Science as Culture*, *27*(2), 175–197. https://doi.org/10.1080/09505431.2017.1354844

Kutty, A. A., Abdella, G. M., Kucukvar, M., Onat, N. C., & Bulu, M. (2020). A system thinking approach for harmonizing smart and sustainable city initiatives with United Nations sustainable development goals. *Sustainable Development*, *28*(5), 1347–1365. https://doi.org/10.1002/sd.2088

Lee, H., Ham, H., & Kwon, H. (2020). Research trends of integrative technology education in South Korea: a literature review of journal papers. *International Journal of Technology and Design Education*, *32*(2), 791–804. https://doi.org/10.1007/s10798-020-09625-7

Lee, J. J., & Haupt, J. P. (2019). Winners and losers in US-China scientific research collaborations. *Higher Education*, *80*(1), 57–74. https://doi.org/10.1007/s10734-019-00464-7

Li, L. (2017). China's manufacturing locus in 2025: With a comparison of "Made-in-China 2025" and "Industry 4.0." *Technological Forecasting and Social Change*, *135*, 66–74. https://doi.org/10.1016/j.techfore.2017.05.028

Mbanefo, M. C., & Eboka, O. C. (2017). Acquisition of Innovative and Entrepreneurial Skills in Basic Science Education for Job Creation in Nigeria. *Science Education International, 28*(3)*,* 207-213. https://doi.org/10.33828/sei.v28.i3.4

Musa, A., Victor, B., & Ali, H. (2016). Education, Science and Technology: a triadic process for promoting socio-economic skills in Nigeria. *Issues in Scientific Research, 1*(4), 52-60. https://doi.org/10.15739/isr.16.006

Nwafor, C. E., & Okoi, O. O. (2018). Science and Technical Education Beyond the Classroom: A Case Study of Mechanic Village, Abakaliki, Ebonyi State, Nigeria. *Middle-East Journal of Scientific Research, 26*(7), 688–697. https://doi.org/10.5829/idosi.mejsr.2018.688.697

Obori, I. A. O. (2012). Re-Engineering Science Education for Employment and Self-productivity in Nigeria.

African Education Indices, 4(1), 119-128.

Okafor, C. F. (2018). Science education: A tool for skill acquisition and entrepreneurship development of Nigerian students. *Nnadiebube Journal Education in Africa, 3*(2), 19–38.

Olofin, S. O., Ogunjobi, A.O., Falemu, F.A., & Akinwumi, I. O. (2023). Science education as a tool for achieving socio-economic development in Nigeria. *International Journal of Development and Economic Sustainability 11*(4), 33-44. Retrieved from https://doi.org/10.37745/ijdes.13/vol11n43344

Onyebuchi, N. C., Unachukwu, C. C., & Osawaru, B. (2024). STEM education advancements in African contexts: A comprehensive review. *World Journal of Advanced Research and Reviews*, *21*(1), 145–160. https://doi.org/10.30574/wjarr.2024.21.1.2719

Sen, S., Chakraborty, R., & De, B. (2011). Challenges and opportunities in the advancement of herbal medicine: India's position and role in a global context. *Journal of Herbal Medicine*, *1*(3–4), 67–75. https://doi.org/10.1016/j.hermed.2011.11.001

Shamsuddin, I. M., Arome, A. T., & Aminu, I. (2018). Entrepreneurship, Science and Technology Education for Self-Reliance and Economic *Diversification. International Journal of Engineering Management, 2*(1), 1-7. https://doi.org/10.11648/j.ijem.20180201.11

Solga, H., Protsch, P., Ebner, C., & Brzinsky-Fay, C. (2014). *The German vocational education and training system: Its institutional configuration, strengths, and challenges*. ECONSTOR. Retrieved March 27, 2025, from https://www.econstor.eu/handle/10419/104536

Umar, Y. (2019). STEM Education as a Catalyst for National Development: Problems and Prospects in Nigeria. *Learning Science and Mathematics, 14*, 48–59.

Urbanova, M. (2018). *Japan's Legacy of Technology in the Digital Era : A Mixed Methods Analysis of the Competitive Advantage of the IoT Sector in Japan*. LUP Student Papers. http://lup.lub.lu.se/student-papers/record/8953276

Williamson, P. J., & Yin, E. (2014, April 23). *Accelerated Innovation: the new challenge from China*. MIT Sloan Management Review. Retrieved March 28, 2025, from https://sloanreview.mit.edu/article/accelerated-innovation-the-new-challenge-from-china/

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The Application of Socioscientific Issues (SSI)-Based Learning to Develop Scientific Argumentation Skills in the Production of Bio-foam (Biodegradable Styrofoam) from Sugarcane Bagasse

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Abstract

SSI-based learning focuses on the complex problems that develop throughout society. SSI holds significant implications for society, requiring students, as the future generation, to actively participate in dialogue, discussion, debate, and argumentation. The purpose of this study is to analyse the development process of scientific argumentation skills in the production of bio-foam using sugarcane bagasse (Saccharum officinarum Linn). We have adopted a pre-experimental methodology, utilising a one-shot case study design. Students' observation sheets and SSI-based worksheets serve as research instruments, assessing their scientific analytical skills. The research findings reveal that students' implementation of SSI-based learning in the production of bio-foam from sugarcane bagasse demonstrates high competency and adherence to the learning stages. The average score of 87.6 fell into a very good category. The proficiency in completing the SSI-focused worksheets achieved an average score of 89.3; it was also classified as very good. The implementation of an SSI-focused study has led to the attainment of level 4 analytical skills in scientific argumentation for sugarcane bagasse production. This study reveals that students are capable of presenting argumentation skills with a single, clear counterargument. Therefore, implementing SSI-based learning in the production of sugarcane bagasse can enhance the development of scientific argumentation skills.

Keywords: Bio-foam; Scientific Arguments; Socioscientific Issues; Sugarcane Bagasse

Introduction

In the era of the 4.0 industrial revolution, skills are needed that lead people to achieve success in their life. Thus, in the 21st century, students are required to possess skills in creative thinking, critical thinking and problem-solving, communication, and collaboration, commonly referred to as the 4C (Afida, 2023). The 4C skills, including communication skills, can be developed through education in institutions. Communication skills are one of the abilities that students need to convey arguments from observations based on both oral and written analysis activities (Widhi et al., 2021). According to Bricker and Bell (2008), it is also stated that communication skills are the most important process in science learning and can help students achieve a better understanding.

According to Amalia et al. (2019), science is not just about discovering and presenting facts, but also about building arguments and considering them, as well as debating various explanations of phenomena. Erduran (2004) stated that scientists use argumentation to support theories, models, and explain natural facts. The process of building knowledge in science education involves developing an explanation by creating reasonable data and then presenting it to the community for critique, debate, and revision (Driver, 2000).

Argumentation skills are one of the techniques to showcase students' argumentation in communication skills, which can encourage these students to observe and seek facts and evidence, as well as beliefs. Therefore, these skills emerge from the understanding of concepts, ideas, or situations, allowing students to become accustomed to arguing (Qodriyah, 2018). In addition, Siska et al. (2020) found that students experience difficulties in scientific argumentation. This can be seen when students explain scientific phenomena, such as with the students from Muhammadiyah 3 Senior High School of Yogyakarta, who are still relatively unaccustomed to expressing scientific arguments in the classroom learning process.

In addition, many students still face difficulties in this regard, so teaching needs to start focusing on involving students in scientific argumentation as part of science. (Siska et al., 2020). As well as the difficulties with argumentation, students' analytical skills are at a low standard. Based on the research conducted by Sandoval & Millwood (2005), it was found that high school students in developed countries experience difficulties in constructing scientific arguments and face challenges in explaining scientific phenomena empirically in class discussions.

The low scientific argumentation skills of students are related to the lack of learning experience and the dominance of teachers in the learning process, which results in students' understanding of the material being less profound. As a result, their analytical skills are weak, so their scientific argumentation skills do not develop (Erduran et al., 2005). One way to develop scientific argumentation skills is through learning based on socio-scientific issues. The socioscientific issues approach is an approach that highlights issues or problems that arise within society. Socioscientific issues aim to stimulate intellectual, moral, and ethical development by raising awareness of the relationship between science and social life (Zeidler et al., 2005). In addition, the socioscientific issues approach has the potential to train skills for solving problems faced by students during the learning process. The syntax of examples of socioscientific issues includes information orientation, material review, exploration of ethical values, discussion, statement construction, ethical study, decision-making, and reflection (Aisya et al., 2017).

According to Hanifah et al. (2021), the socio-scientific issues-based learning model has a significant impact on problem-solving abilities using the Powtoon application. According to Afrilya (2020), there is an influence of applying the SSI issues learning approach on students' science literacy skills regarding petroleum material. The research results show that there is a positive influence, which can be observed from the comparison of the t-value and the t-table, with a t-value of -22.942, while the t-table value at a 5% significance level is 2.0301. The improvement in science literacy can be categorised as 'high', as evidenced by an N-Gain value of 0.7352. Other researchers also argue that learning based on SSI issues can enhance students' scientific argumentation skills because when the learning takes place using the SSI issues model, it can present students with a social problem from the perspective of scientific knowledge or scientific background (Siska et al., 2020).

In order to achieve the development of scientific argumentation skills in students, the presence of professional educators is needed so that the learning process can integrate social issues with science material. Therefore, a model of learning approach based on SSI issues is required. One of the social issues that is currently emerging is related to environmental damage caused by waste, especially plastic waste. Plastic has many benefits for human life. However, plastic derived from the synthesis of petroleum hydrocarbon polymers also has negative impacts on the environment due to its limited quantity, non-renewable nature, and slow decomposition. One example of plastic is styrofoam, which comes from the type of plastic polystyrene (PS). Styrofoam is widely used as a container for various types of food. However, the use of styrofoam is highly discouraged because it has negative plastic properties. Therefore, there is a need to replace styrofoam with food containers made from natural sources such as sugarcane bagasse as a fiber raw material that has the characteristic of being biodegradable in nature (Tibalia, 2024).

The sugar industry can produce bagasse at around 32% of the weight of the milled sugarcane. Sugarcane bagasse, also known as bagasse, is a byproduct of the sugarcane juice extraction process. Sugarcane bagasse mostly contains lignocellulose. The fiber length is between 1,7-2 mm with a diameter of about 20 μm, so this sugarcane bagasse can meet the requirements to be processed into engineered boards. Bagasse fiber is insoluble in water and mostly consists of cellulose, pentosan, and lignin (Bahri et al., 2021). Sugarcane bagasse has a physical appearance that is yellowish, fibrous, soft, and requires a soft place for storage in the form of charcoal in the same quantity. Sugarcane bagasse is a complex lignocellulosic compound. Cellulose is the main component of the structure of woody plant tissues, and this material is also found in shrubs such as ferns, mosses, algae, and fungi.

The addition of protein and fiber is to improve the physical and mechanical properties of the resulting bio-foam. Increasing the fiber concentration can enhance the mechanical properties of the product and reduce the moisture content after the printing process. Increasing the protein concentration can reduce the moisture content after printing, water absorption capacity, and spoilage rate. Therefore, the processing of sugarcane bagasse waste is one of the social issues applied in SSI issues-based learning to develop scientific argumentation skills. The novelty of this research lies in the scientific argumentation skills of students resulting from SSI issues-based learning applied in the production of bio-foam from sugarcane bagasse.

The application of SSI issues-based learning to develop scientific argumentation skills in the production of bio-foam from sugarcane bagasse was conducted with students participating in science extracurricular activities. Through the SSI issues approach, learning not only focuses on scientific concepts but also explores pro and con perspectives related to these issues, creating space for the development of students' critical thinking toward real-world problems (Rahayu, 2019). That is already in line with scientific argumentation skills, which include students' ability to construct coherent arguments, present relevant evidence, and formulate conclusions based on strong logic and scientific evidence.

There are several indicators of scientific argumentation skills, including: a) Claim, which contains a statement or decision believed by the individual making the argument; b) Evidence, which is scientific data that supports the claim; c) Reasoning, which is the justification that connects the claim with the evidence; and d) Rebuttal, which is a statement that opposes the data or an explanation regarding the relationship between the data and the claim (Acar & Patton, 2012). Furthermore, this study applied the learning based on socio-scientific issues. In more detail, the implementation of this learning refers to each phase of the SSI issues-based student worksheet, which is analysed at each stage. The SSI issues-based student worksheet has 5 stages: (1) problem approach and analysis; (2) problem clarification; (3) continuation of the issue; (4) discussion and evaluation; and (5) reflection (Rostikawati & Permanasari, 2016).

Methodology

In this study, a pre-experiment method was used, specifically a one-shot case study, where a group was given treatment and then observed for the results (Creswell, 2012; Sugiyono, 2017). 20 students from Muhammadiyah 3 Senior High School in Yogyakarta participated in this study as part of their science curriculum in 2024. Therefore, the researchers were focused on one class that was given the treatment and observed how students learned SSI to develop their scientific argumentation skills in the application of production of bio-foam (biodegradable styrofoam) from sugarcane bagasse. Furthermore, the researchers conduct this research in three stages: the planning stage, the implementation stage using a learning model, and the concluding step. The following steps that need to be performed are as follows:

1. Planning Stage

The planning stage encompasses a preliminary investigation designed to acquire a comprehensive understanding of the research topic through a literature review, which involves analysing relevant papers related to current or historical social issues and examining educational models grounded in SSI. The students' activities in observation sheets and worksheets were confirmed and revised by subject matter experts. Therefore, a trial was performed for the validation of the instrument.

2. Implementation Stage

The SSI-based learning model guides the conduct of learning activities during the implementation stage. The stages in the learning implementation follow the thinking framework model from Burke et al. (2014), which incorporates science and technology practice in teaching integration. This is achieved by combining the instructional inquiry model from Burke et al. (2014), which combines the instructional 6E steps: consisting of engaging, exploring, explaining, engineering, enriching, and evaluating. Furthermore, this is also achieved by adopting the context of the socio-scientific issue suggested by Zeidler (2016,) which engages students' scientific literacy in science learning.

a. Phase 1: Analysis Issues

During this phase, the teacher instructs students to read and comprehend the discourse, which takes the form of an article in the worksheet. The expectation is that the students will ask questions after reading the article.

b. Phase 2: Clarify Issues

During this phase, the teacher instructs students to gather information from multiple reliable sources under their guidance and to engage in practical activities. The objective is to assist students in responding to the questions presented and sharing these answers with other groups to pinpoint their issues.

c. Phase 3: Identify Social Issues

In this phase, the goal is for students to identify the information from the book or worksheet, identify the connection between articles 1 and 2, and determine how to address or innovate it.

d. Phase 4: Discussion and Evaluation

During this phase, teachers teach students to explore various alternatives for problem-solving, such as the internet, journals, or books, which can aid in formulating answers. Students formulate solutions to existing problems, consult with educators or teachers, and choose solutions based on their guidance.

e. Phase 5: Reflection

Students present the analysis results from each of their groups in this phase, along with arguments backed by credible sources, to which other students respond. After that, the educator provides reinforcement and corrects any incorrect concepts.

3. Concluding Step

At the final stage, students are asked to draw conclusions and analyse the research data related to learning SSI to develop their scientific argumentation skills in the application of the production of bio-foam (biodegradable styrofoam) from sugarcane bagasse.

The primary data from students participating in science extracurricular activities was utilised within the student scientific group, as well as the secondary data from observation sheets of students' activities and worksheets. In this part, the students were asked to fill out the worksheets while being observed during the learning implementation by using the questionnaire to explore their argumentation skills. The secondary data were directly collected based on data and research results relevant to the application of SSI-based learning, resulting in quantitative data processed statistically. To obtain the primary data, a description of the learning process, observation sheets, and students' worksheets of learning activities are required. Therefore, the students' activities were assessed by identifying the observation sheets and students' worksheets during the learning process and calculating the total scores. Then, the percentage was calculated using the calculation equation (Sugiyono, 2017). It is also possible to learn how to argue scientifically by looking at the level of each indicator on the students' answer sheets using the rubric and the quality level of their written arguments, which were made using Toulmin's Argument Pattern (TAP) and the levels of scientific argumentation quality (Farida 2015) shown in the table below.

Results and Discussion

The results of this study discuss the students' activities during the implementation of a learning model based on SSI activities and show the students' skills of scientific argumentation in the production of sugarcane bagasse, which have achieved level 4 analytical skills. This study shows that application of the instructional 6E model in the SSI context could improve students' scientific argumentation at level 4 of the analytical skills, as shown in Table 2 (Burke et al., 2014; Zeidler, 2016).

The implementation of SSI-based learning consists of five stages: (1) analysing issues; (2) clarifying issues; (3) identifying social issues; (4) discussion and evaluation; and (5) reflection. During the initial phase of learning, problem analysis and clarification are performed. Afterwards, during the second meeting, the stages of learning involve the continuation of analysis of the issues and evaluative discussions. In the third meeting, the stages of reflection and assessments to assess scientific argumentation skills take place, following the Toulmin Argumentation Pattern (TAP), as illustrated in Table 3. Meanwhile, 20 students are organised into four groups during the process of learning, each including five individuals. The outcomes of producing bio-foam (biodegradable styrofoam) from sugarcane bagasse through SSI-based learning formed a total students' score of 87.6 for overall steps of the implementation, which indicated very good results, as illustrated in Table 2. However, most students received good results in the reflection step and lower results in the analysis issues steps, which indicated that students found it hard to think about their argumentation skills. Additionally, the evaluation of activities during SSI-based learning is conducted by an observer assigned to observe students' actions during the learning process. Creswell (2012) incorporates this observer to provide a more accurate and comprehensive depiction of an event or occurrence. The observation method involves straight observation and documentation, devoid of any participation in the experienced event (Hasanah, 2017).

Scientific argumentation skills are analysed through the results of scientific argumentation skills tests. The test is conducted in stage 4: discussion and evaluation in learning. The goal of implementing SSI-based learning is to develop students' abilities in scientific argumentation skills. Classification of categories for the development of scientific argumentation skills based on the level of argumentation quality, referring to TAP as outlined in Table 1. Level of Scientific

Argumentation Quality. Based on the research results, students' scientific argumentation skills can be analysed when students engage in group work through discussions and presentations, focusing on these kinds of students' abilities: (a) presenting arguments clearly from group discussions; (b) answering questions or objections accurately and correctly; and (c) appreciating others' opinions, questions, or objections. The results of the students' performance during the debate are presented in Table 3.

Table 1. Level of Scientific Argumentation Quality

Indicator	Characteristics
Level 0	Argumentation is just a claim.
Level 1	Argumentation consists of arguments in the form of simple claims with opposing claims.
Level 2	If the arguments are in the form of claims accompanied by data, counterclaims, and explanations (reasoning), but do not contain rebuttals.
Level 3	If the arguments contain a series of claims or counterclaims accompanied by data and explanations (reasoning) with occasional weak rebuttals.
Level 4	If the arguments contain claims accompanied by one clearly identifiable and precise rebuttal, one argument contains several claims or counterclaims.
Level 5	If the argumentation is extensive (extended, but still related to the learning material), with more than one clear and precise rebuttal.

Table 2. The Significance of Implementing Student Activities in SSI-Based Learning

No	Implementation Stage	Group Activity Score				Mean	Category
		1	2	3	4		
1	Analysis Issues	78	81	76	78	78.3	Good
2	Clarify Issues	89	92	86	86	88.3	Very good
3	Identify Social Issues	85	85	95	95	90	Very good
4	Discussion and Evaluation	90	95	88	85	89.5	Very good
5	Reflection	90	88	100	90	92	Very good
	Average Score					87.6	

Table 3. Students' Scientific Argumentation Skills in the Implementation of SSI

No	Indicator of Argumentation	Aspect of Argumentation	Mean	Category
1	Claim	Ability to present group discussion arguments clearly	92	Very good
2	Evidence and Reasoning	Answer questions or objections accurately and correctly	78	Good
3	Rebuttal	Ability to respect others' opinions, questions, or objections	98	Very good
	Average Score		89	Very good

Based on the data in Table 3, it can be concluded that the average achievement of students' scientific argumentation skills falls into the very good category with a score of 89. The prominent aspect of students' performance during argumentation is the third aspect, which is the ability of the study group to appreciate the opinions, questions, or objections of others. This is related to the indicator of scientific argumentation skills (rebuttal). An example of expressing an opinion during a discussion could be: "I disagree with using sugarcane bagasse as bio-foam because it is quite difficult to find in my area. Perhaps it could be replaced with paper pulp to make it more accessible." On the other hand, another student's opinion is, "I agree with the alternative of sugarcane bagasse as bio-foam because currently the use of styrofoam is very prevalent and causes environmental pollution, like the trash that is everywhere." Therefore, based on the level of scientific argumentation, the student's answer has reached level 4, which is based on claims accompanied by reasons that can be clearly and accurately identified, with one argument containing several claims or counterclaims.

This study is in line with the research by Novianti et al. (2022), stating that students can write claims, supporting data for claims, and justifications to correctly connect them, but are not yet able to write data and support to strengthen the argumentation. Similarly, Skills (2009) divided the components of critical thinking into: (1) analysis and evaluation; (2) evidence; (3) argument; (4) claim and belief; (5) synthesis and creation connection of information and opinion; (6) interpretation of data, reflection, learning experience, and process, which focused on building 21^{st} century skills; (7) content knowledge; and (8) expertise. However, Shaughnessy et al. (2017) explained that the components of interpretation, evaluation, analysis, inference, and explanation could be used to recognise the information of observational inferences and the credibility of the information by using scientific thinking and the logical interrelationship of facts from various experiments.

The analytical results related to each level of learning on the production of bio-foam (biodegradable styrofoam) derived from sugarcane bagasse. The average student's proficiency in completing the worksheets corresponds to the learning phases, as evidenced by a total score of 89.3, classified as very good according to the reference in Table 3. In another hand, the assessment of the quality of students' scientific arguments refers to the categories developed by Farida (2015). The arguments analysed are those produced by students in study groups, either orally through presentations or in writing, based on the results of scientific argumentation skills tests. Therefore, Afrilya (2020) states that learning using SSI aims to involve students in the decision-making process, show students the importance of their decisions, and train them to study a problem thoroughly, including aspects related to students' moral values. This implies that learners must acquire the ability to make decisions and hone practical skills that ultimately align with their moral attitudes.

In general, the ability to speak scientific argumentation abilities of the students are predicated upon their learning groups; however, one learning group that has achieved level 4 is of particular concern. Level 4 argumentation is characterised by the inclusion of numerous claims or counterclaims, each of which is accompanied by a distinct and precise rebuttal (Farida, 2015). The results of the observation indicate that the quality of the arguments that students construct is not substantially affected by the presence of study groups. Only a small number of individuals in each group are capable of articulating their arguments. Subsequently, there is no correlation between students' engagement with their arguments and their decision to establish a group (Hakyolu & Bekiroglu, 2011)

Conclusion

This research has discussed the application of SSI-based learning to develop scientific argumentation skills in the production of bio-foam (biodegradable styrofoam) from sugarcane bagasse. Based on the results, this study can be concluded that students' activities during the SSI-based learning process received an average score of 87.6, categorised as very good. The highest average score occurred in the reflection phase at 92, while the lowest average score occurred in the analysis issues phase at 78.3, categorised as good. On the other hand, the students' ability to complete the SSI-based Student Work Sheet on the production of bio-foam (biodegradable styrofoam) from sugarcane bagasse received an average score of 89.3, which was classified as very good. The highest average score occurred in the identify social issues phase at 94, categorised as very good, while the lowest score occurred in the analyse social issues phase at 79, categorised as good. However, by implementing a study focused on SSI, it was found that the skills of scientific argumentation in the production of sugarcane bagasse have achieved a level 4 analytical skills, which indicated students' abilities to construct clear arguments. Therefore, the authors recommended that educators or researchers focus on the implementation of SSI-based learning in class activities, especially in the context of science learning, which relates to phenomena in daily lives that students can improve their argumentation skills. However, other researchers could continue to promote SSI-based learning in developing the issues that have been debated and unsolved problems to improve students' 21st-century communication skills, especially argumentation skills as described in this article.

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References

Acar, O., & Patton, B. R. (2012a). Argumentation and Formal Reasoning Skills in an Argumentation-Based Guided Inquiry Course. *Procedia-Social and Behavioral Sciences, 46(*10), 4756–4760.

Afida, R. N. (2023, June). Literature review: Peran guru dalam membangun ketrampilan 4c siswa dengan pembelajaran berdiferensiasi. *In Prosiding Seminar Nasional Pascasarjana 6*(1), 643-647.

Afrilya, N. A. (2020). *Pengaruh Penerapan Pendekatan Socio Scientific Issues (SSI) Terhadap Kemampuan Literasi Sains Siswa pada Materi Minyak Bumi* (Doctoral dissertation, Universitas Islam Negeri Sultan Syarif Kasim Riau).

Aisya, N., Wibowo, Y., & Aminatun, T. (2017). The Influence of Socio-Scientific Issues on Reflective Judgment of High School's Student in Ecosystem Material. *Jurnal Bioedukatika, 4*(2), 1-14.

Amalia, R., Rahmawati, Y., & Budi, S. (2019). Pengembangan keterampilan argumentasi calon guru kimia melalui pendekatan socio critical and problem oriented. *JTK (Jurnal Tadris Kimiya), 4*(1), 91-104.

Bahri, S., Aji, A., & Yani, F. (2019). Pembuatan Bioetanol dari Kulit Pisang Kepok dengan Cara Fermentasi menggunakan Ragi Roti. *Jurnal Teknologi Kimia Unimal, 7*(2), 85.

Bahri, S., Fitriani, F., & Jalaluddin, J. (2021). Pembuatan Biofoam Dari Ampas Tebu Dan Tepung Maizena. *Jurnal Teknologi Kimia Unimal, 10*(1), 24-32.

Bricker, L. A., & Bell, P. (2008). Conceptualizations of argumentation from science studies and the learning sciences and their implications for the practices of science education. *Science Education, 92*(3), 473–498.

Burke, B. N., Reed, P. A., & Wells, J. G. (2014). Integrating technology and engineering in a STEM context.

Creswell, J. W. (2012). *Educational Research: Planning, Conducting, and Evaluating Quantitative and Qualitative Research (4th ed.).* Boston: Pearson.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science education, 84*(3), 287-312.

Erduran, S., Osborne, J., & Simon, S. (2005). The role of argumentation in developing scientific literacy. *Springer, 1,* 381–382.

Farida, I. (2015). Profil Keterampilan Argumentasi Siswa Pada Konsep Koloid Yang Dikembangkan Melalui Pembelajaran Inkuiri Argumentatif. *EDUSAINS, 6*(1), 31–40.

Hakyolu, H., & OganBekiroglu, F. (2011). Assessment of Students' Science Knowledge Levels and their Involvement with Argumentation. *International Journal for Cross-Disciplinary Subjects in Education, 2*(1), 264–270.

Hanifah, E., Setiono, S., & Nuranti, G. (2021). Pengaruh Model Socio-Scientific Issue Terhadap Keterampilan Memecahkan Masalah Menggunakan Aplikasi Powtoon pada Materi Perubahan Lingkungan. *Biodik, 7*(4), 18–28.

Hasanah, H. (2017). Teknik-Teknik Observasi (Sebuah Alternatif Metode Pengumpulan Data Kualitatif Ilmu-ilmu Sosial). *At-Taqaddum, 8*(1), 21.

Novianti, D., Mulyani, B., & VH, E. S. (2022). Analisis Kemampuan Argumentasi Ilmiah Peserta Didik Kelas X MIPA SMA Negeri 2 Surakarta Pada Materi Hukum Dasar Kimia. *Jurnal Pendidikan Kimia, 11*(1), 75–81.

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching, 41*(10), 994–1020.

Qodriyah, A. L. (2018). *Analisis Wacana Argumentasi Peserta Didik pada Diskusi Isu-Isu Sosiosaintifik.* Skripsi. Jakarta: Ilmu Tarbiyah dan Keguruan UIN Syarif Hidayatullah).

Rahayu, Sri. (2019). Socioscientific Issues : Manfaatnya dalam Meningkatkan Pemahaman Konsep Socioscientific Issues : Manfaatnya dalam Meningkatkan Pemahaman Konsep Sains , Nature of Science (NOS) dan Higher Order Thinking Skills (HOTS). *Seminar Nasional Pendidikan IPA UNESA, October, 2*.

Rostikawati, D. A., & Permanasari, A. (2016). Rekonstruksi bahan ajar dengan konteks socio-scientific issues pada materi zat aditif makanan untuk meningkatkan literasi sains siswa. *Jurnal Inovasi Pendidikan IPA, 2*(2), 156.

Sandoval, W. A., & Millwood, K. A. (2005). The quality of students' use of evidence in written scientific explanations. *Cognition and instruction, 23*(1), 23-55.

Shaughnessy, M. F., Varela, M., & Liu, Z. (2017). Critical Thinking in Science: What Are the Basics? *World Journal of Educational Research, 4*(4).

Siska, S., Triani, W., Yunita, Y., Maryuningsih, Y., & Ubaidillah, M. (2020). Penerapan pembelajaran berbasis socio scientific issues untuk meningkatkan kemampuan argumentasi ilmiah. *EduSains: Jurnal Pendidikan Sains & Matematika, 8*(1), 22-23.

Skills, P. f. s. C. (2009). *P21 framework definitions*: ERIC Clearinghouse.

Sugiyono. (2017). Metode penelitian kuantitatif, kualitatif, dan R&D. *Alfabeta*.

Tibalia, E. M. S. E. (2024). Evaluasi Biodegradable Food Container Pengganti Styrofoam dari Jerami Padi dan Ampas Tebu Dengan Penambahan Kitosan dan Kulit Jeruk (Doctoral dissertation, Universitas Gadjah Mada).

Widhi, M. T. W., Hakim, A. R., Wulansari, N. I., Solahuddin, M. I., & Admoko, S. (2021). Analisis keterampilan argumentasi ilmiah peserta didik pada model pembelajaran berbasis toulmin's argumentation pattern (TAP) dalam memahami konsep fisika dengan metode library research. *PENDIPA Journal of Science Education, 5*(1), 79-91.

Zeidler, D. L. (2016). STEM education: A deficit framework for the twenty first century? A sociocultural socioscientific response. *Cultural Studies of Science Education, 11*(1), 11-26.

Zeidler, D. L., Sadler, T. D., Simmons, M. L., & Howes, E. V. (2005). Beyond STS: A research-based framework for socioscientific issues education. *Science Education, 89*(3), 357–377.

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