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Case-Based Learning for Enhancing Occupational Health Biomedical Literacy: Evidence from Exercise-Induced Oxidative Stress Education

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Abstract:

Occupational fatigue and oxidative stress have become important concerns in Occupational Health and Safety (OHS) education due to their impact on workers' physiological health and workplace performance. However, biomedical learning in OHS programs is often theoretical and lacks contextual learning experiences that promote scientific reasoning and biomedical literacy. This study aimed to investigate the effect of Case-Based Learning (CBL) on occupational health biomedical literacy among OHS students in the context of exercise-induced oxidative stress. A quasi-experimental pretest–posttest control group design was employed involving 42 undergraduate OHS students divided into an experimental group ($n = 21$) and a control group ($n = 21$). The experimental group received CBL instruction using authentic biomedical cases related to Malondialdehyde (MDA), Serum Glutamic Pyruvic Transaminase (SGPT), $VO_2\text{max}$, and occupational fatigue, while the control group received conventional lecture-based instruction. Data were collected using a biomedical literacy test assessing conceptual understanding, biomedical data interpretation, scientific reasoning, and occupational health decision-making. The results showed that the experimental group achieved a higher posttest score (84.52 ± 6.73) than the control group (71.38 ± 7.84). The normalized gain was also higher in the experimental group (0.65) than in the control group (0.35). Paired-samples t-test analysis revealed significant improvements in biomedical literacy scores in both groups ($p < 0.001$), with substantially greater gains observed in the CBL group. These findings indicate that integrating authentic biomedical cases through CBL effectively enhances biomedical literacy and scientific reasoning among OHS students and may serve as an effective strategy for contextual occupational health education.

INTRODUCTION

The increasing prevalence of occupational fatigue, work-related physiological stress, and lifestyle-related health disorders has become a major concern in occupational health and safety (OHS) education. Modern workers, particularly those engaged in physically demanding occupations, are frequently exposed to excessive workloads, repetitive movements, prolonged physical exertion, and inadequate recovery periods, all of which contribute to physiological imbalance and oxidative stress (Powers et al. 2016). Oxidative stress occurs when the

production of Reactive Oxygen Species (ROS) exceeds the body's antioxidant defense system, leading to cellular and tissue damage (Cui et al. 2015). In occupational contexts, prolonged oxidative stress may contribute to fatigue, reduced work performance, musculoskeletal disorders, metabolic dysfunction, and chronic degenerative diseases (Karasu et al. 2025). Therefore, understanding the physiological mechanisms underlying oxidative stress has become increasingly important for Occupational Health and Safety students, as future professionals are expected to identify, analyze, and prevent health risks associated with excessive physical strain in workplace environments.

Exercise induced oxidative stress has been widely recognized as one of the primary physiological mechanisms associated with increased free radical production. During intense physical activity, oxygen consumption in skeletal muscles increases substantially, resulting in elevated ROS formation and lipid peroxidation (Ayala et al. 2014; Susiati et al. 2023). This process subsequently triggers cellular membrane damage and increases biomarkers such as Malondialdehyde (MDA) and Serum Glutamic Pyruvic Transaminase (SGPT), which are commonly used as indicators of oxidative stress and tissue injury. Previous studies demonstrated that prolonged cycling activities significantly increased MDA and SGPT levels, particularly among older participants and individuals with lower physical fitness levels (Susiati et al. 2023). These findings indicate that oxidative stress is not only relevant in sports physiology but also highly applicable to occupational health contexts, especially for workers exposed to physically demanding tasks and environmental stressors.

Despite the growing importance of biomedical understanding in occupational health, OHS education in higher education institutions remains predominantly theoretical and often lacks contextual biomedical learning experiences (Susiati, Hardianto, et al., 2025). Many students encounter difficulties in interpreting physiological data, understanding biomarker relationships, and connecting scientific concepts to real world occupational health problems. As a result, students' biomedical literacy, particularly regarding oxidative stress, physiological adaptation, and occupational fatigue mechanisms, remains relatively limited (Hardjo et al. 2025). Biomedical literacy refers to an individual's ability to understand, interpret, evaluate, and apply biomedical information for evidence-based decision-making (Shannon et al. 2024). In the context of occupational health education, biomedical literacy is essential because future OHS professionals are required to analyze physiological risk factors, interpret health indicators, and formulate preventive strategies to minimize workplace-related health problems.

To address these educational challenges, innovative instructional approaches that promote active engagement and contextual understanding are urgently needed. One promising approach is Case-Based Learning (CBL), which emphasizes authentic problem solving through real world scenarios (Carenzo et al. 2022). Rooted in constructivist learning theory, CBL encourages students to actively construct knowledge by analyzing realistic cases, discussing scientific evidence, and making reasoned decisions based on data interpretation (Donkin et al. 2023). Previous studies have reported that CBL can improve critical thinking, scientific reasoning, problem-solving ability, and student engagement in health and science education (Zheng and Mavis 2022). Through contextual cases, students are encouraged not only to

memorize biomedical concepts but also to apply them in practical and occupationally relevant situations (S. Das et al. 2022).

Incorporating exercise induced oxidative stress cases into occupational health education may provide meaningful contextual learning opportunities for students (Panahi et al. 2022). Real physiological data such as MDA levels, SGPT concentrations, VO₂max values, and exercise performance indicators can be utilized as authentic learning materials to help students understand the relationship between physical activity, oxidative stress, and occupational health risks. By engaging with authentic biomedical cases, students are expected to develop stronger analytical skills, improve their ability to interpret scientific data, and enhance their awareness of occupational health prevention strategies. Furthermore, integrating biomedical case analysis into OHS education may bridge the gap between theoretical biomedical sciences and practical workplace health applications.

Although previous studies have extensively examined exercise-induced oxidative stress from physiological and biomedical perspectives, their primary focus has been on identifying biomarkers, physiological responses, and health outcomes associated with oxidative stress. For example, (Susiati et al. 2023) investigated changes in Malondialdehyde (MDA) and Serum Glutamic Pyruvic Transaminase (SGPT) following prolonged cycling activities, (Panahi et al. 2022) examined educational interventions aimed at reducing oxidative stress among healthcare workers. In contrast, studies on Case-Based Learning (CBL) have largely focused on improving critical thinking, clinical reasoning, and problem-solving skills in medical and health professions education (D. Das and Sengar 2022; Tsekhmister 2023; Zheng and Mavis 2022). However, these studies did not specifically integrate authentic oxidative stress data into occupational health learning nor evaluate its impact on biomedical literacy. Therefore, a significant gap remains regarding how authentic biomedical cases related to exercise-induced oxidative stress can be utilized through Case-Based Learning to enhance biomedical literacy among Occupational Health and Safety students. This study addresses that gap by integrating physiological biomarkers (MDA, SGPT, and VO₂max) into contextual occupational health cases and examining their effectiveness in improving students' conceptual understanding, biomedical data interpretation, scientific reasoning, and occupational health decision-making. Consequently, the novelty of this study lies in the integration of authentic exercise-induced oxidative stress data with Case-Based Learning to strengthen occupational health biomedical literacy, an area that has received limited attention in previous educational research.

Therefore, this study aims to investigate the effect of Case-Based Learning on occupational health biomedical literacy among Occupational Health and Safety students in the context of exercise-induced oxidative stress. Specifically, this study examines whether contextual biomedical case analysis can improve students' conceptual understanding, scientific reasoning, data interpretation skills, and occupational health decision-making abilities related to oxidative stress and physiological responses to physical activity. Through this approach, the study is expected to contribute both theoretically and practically to the development of contextual biomedical education in Occupational Health and Safety programs.

METHODS

This study employed a quasi-experimental design using a pretest–posttest control group approach to examine the effect of Case-Based Learning (CBL) on occupational health biomedical literacy among Occupational Health and Safety (OHS) students. The experimental group received CBL instruction, while the control group received conventional lecture-based learning. The participants consisted of 42 undergraduate OHS students from Universitas Famika selected through purposive sampling. The inclusion criteria were: (1) enrollment as an active undergraduate student in the OHS program, (2) completion of the Basic Human Physiology course, (3) no prior participation in formal learning activities specifically addressing exercise-induced oxidative stress, and (4) willingness to participate in all stages of the study. The students were divided into two intact classes consisting of 21 students in the experimental group and 21 students in the control group. All participants voluntarily participated in the study and provided informed consent prior to data collection.

The primary instrument was a Biomedical Literacy Test developed based on occupational health and exercise physiology concepts. The instrument was designed to assess students' occupational health biomedical literacy across four dimensions: (1) conceptual understanding, (2) biomedical data interpretation, (3) scientific reasoning, and (4) occupational health decision-making. Observation sheets were also used to assess student engagement during learning activities. The instrument was validated by experts in biology education, occupational health, and biomedical science.

The Biomedical Literacy Test consisted of 25 items comprising multiple-choice questions and case-based open-ended questions. The conceptual understanding section evaluated students' comprehension of oxidative stress mechanisms, Reactive Oxygen Species (ROS), Malondialdehyde (MDA), Serum Glutamic Pyruvic Transaminase (SGPT), and VO₂max concepts. The biomedical data interpretation section assessed students' ability to analyze physiological data, graphs, and biomarker changes associated with physical activity and occupational fatigue. The scientific reasoning dimension measured students' abilities to explain causal physiological relationships and justify biomedical phenomena using scientific evidence. Meanwhile, the occupational health decision-making section evaluated students' abilities to formulate evidence-based recommendations related to fatigue prevention, workload management, recovery strategies, and workplace health protection.

Prior to the intervention, a baseline equivalence analysis was conducted using an independent-samples t-test on the pretest biomedical literacy scores to determine whether the two groups had comparable initial abilities. The results indicated no significant difference between the experimental group ($M = 56.19$, $SD = 8.42$) and the control group ($M = 55.71$, $SD = 7.96$), confirming that both groups possessed equivalent baseline biomedical literacy prior to the intervention ($p > 0.05$).

A pilot test was conducted on 30 students outside the research sample to evaluate the reliability and readability of the instrument. The reliability analysis using Cronbach's alpha demonstrated a coefficient of 0.87, indicating high internal consistency. Item discrimination and difficulty index analyses were also performed to ensure the quality of the test items. Based

on the pilot results, several items were revised to improve clarity and alignment with the learning objectives.

Data were analyzed using SPSS version 26. Descriptive statistics were used to summarize students' biomedical literacy scores. An independent-samples t-test was first conducted to examine baseline equivalence between groups. Subsequently, paired-samples t-tests were performed to determine within-group improvements, while independent-samples t-tests were used to compare posttest scores and normalized gain (N-gain) values between groups. Statistical significance was determined at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Descriptive Statistics of Biomedical Literacy Scores

The results of this study demonstrated that Case-Based Learning (CBL) positively influenced students' occupational health and biomedical literacy. Students who participated in contextual biomedical case analysis showed greater improvement compared to those who learned through conventional lecture-based instruction. The descriptive statistics of students' biomedical literacy scores are presented in Table 1.

Table 1. Pretest and Posttest Biomedical Literacy Scores

Group	N	Pretest Mean $\pm$ SD	Posttest Mean $\pm$ SD	N-Gain
Experimental (CBL)	21	56.19 $\pm$ 8.42	84.52 $\pm$ 6.73	0.65
Control	21	55.71 $\pm$ 7.96	71.38 $\pm$ 7.84	0.35

The findings revealed that both groups experienced improvement after the learning intervention, however the experimental group achieved substantially higher posttest scores and N-gain values than the control group. The experimental class reached a moderate to high improvement category, indicating that the use of authentic biomedical cases effectively strengthened students' understanding of oxidative stress and occupational health concepts.

The improvement in the experimental group may be attributed to the contextual nature of Case-Based Learning, which encouraged students to actively analyze physiological phenomena rather than passively receive theoretical information (Zheng and Mavis 2022). During the learning process, students examined authentic cases related to exercise induced oxidative stress, including changes in Malondialdehyde (MDA), Serum Glutamic Pyruvic Transaminase (SGPT), and VO₂max values. Through this process, students were able to connect biomedical concepts with occupational fatigue and workplace health risks.

These findings are consistent with previous biomedical studies showing that excessive physical activity can increase oxidative stress and tissue damage, indicated by elevated MDA and SGPT levels. By integrating these physiological findings into occupational health education, students developed a more meaningful understanding of how oxidative stress mechanisms may occur in physically demanding work environments (Tsekhmister 2023).

The present findings are also consistent with previous studies reporting the educational benefits of Case-Based Learning in health sciences education. (Zheng and Mavis 2022) found

that CBL promotes deeper conceptual understanding and facilitates the application of theoretical knowledge to real-world situations. Similarly, (Tsekhmister 2023), through a meta-analysis of medical and pharmacy education studies, reported that CBL significantly improves students' analytical thinking and knowledge retention compared with conventional instructional approaches. The higher posttest scores and N-gain values observed in the present study support these findings and suggest that contextual biomedical cases can effectively facilitate meaningful learning among Occupational Health and Safety students. However, unlike previous studies that primarily focused on clinical reasoning and medical decision-making, this study specifically emphasizes biomedical literacy related to occupational physiology and oxidative stress, thereby extending the application of CBL to occupational health education.

Improvement of Biomedical Literacy

The paired samples t-test analysis indicated significant improvements in biomedical literacy scores in both groups after the intervention. However, students in the experimental group demonstrated a substantially greater increase compared to students in the control group.

Table 2. Paired Samples T-Test Results

Group	t-value	Sig. (p)
Experimental (CBL)	12.84	<0.001
Control	5.97	<0.001

Effect size analysis was conducted to determine the magnitude of the intervention effect beyond statistical significance. Cohen's d was calculated based on the difference between pretest and posttest scores. The experimental group demonstrated a large effect size ($d = 1.72$), whereas the control group showed a moderate effect size ($d = 0.83$). These findings indicate that Case-Based Learning produced a substantially greater educational impact on occupational health biomedical literacy than conventional lecture-based instruction.

The significant improvement observed in the experimental group suggests that Case-Based Learning effectively facilitated deeper conceptual understanding and scientific reasoning. Students were not only exposed to theoretical explanations regarding oxidative stress, but they were also required to interpret biomedical evidence, identify physiological relationships, and formulate occupational health recommendations based on authentic cases.

During classroom discussions, students actively analyzed how increased oxygen consumption during physical activity could trigger Reactive Oxygen Species (ROS) production, leading to lipid peroxidation and increased MDA levels. Students also discussed how elevated SGPT levels may indicate tissue damage associated with excessive physiological stress. These discussions encouraged students to understand occupational fatigue not merely as a physical symptom, but as a complex physiological process involving oxidative stress and cellular damage.

The active learning environment created through Case-Based Learning aligns with constructivist learning theory, which emphasizes that knowledge is constructed through experience (Kim 2024), interaction, and contextual problem solving (Greenstein 2012). By

engaging with authentic biomedical cases, students were able to develop analytical thinking skills and connect scientific evidence (Susiati, Azis, et al. 2025) to occupational health issues more effectively than students in conventional classrooms.

The findings are in agreement with (D. Das and Sengar 2022), who reported that Case-Based Learning enhances students' critical thinking, problem-solving abilities, and engagement in health education. (Donkin et al. 2023) also demonstrated that online case-based learning contributes positively to students' knowledge acquisition and clinical reasoning skills. Nevertheless, some studies have reported more modest learning gains, particularly when case discussions are conducted with limited interaction or insufficient facilitator support. For example, several online CBL implementations reviewed by Donkin et al. (2023) showed inconsistent outcomes due to variations in instructional design and student participation. The stronger improvement observed in the present study may be attributed to the use of authentic physiological data, collaborative group discussions, and direct connections between biomedical concepts and occupational health problems, which provided students with more meaningful learning experiences.

Furthermore, the use of authentic physiological data contributed to the development of biomedical literacy skills, particularly in biomedical data interpretation and occupational health decision-making. Students in the experimental group showed improved abilities in interpreting graphs, explaining biomarker changes, and evaluating workplace health risks associated with excessive physical workload.

Performance Across Biomedical Literacy Dimensions

To obtain a more comprehensive understanding of students' learning outcomes, biomedical literacy performance was analyzed across four dimensions: conceptual understanding, biomedical data interpretation, scientific reasoning, and occupational health decision-making. As presented in Table X, students in the experimental group achieved higher gains across all dimensions compared to the control group.

Among the four dimensions, the largest improvement was observed in biomedical data interpretation and scientific reasoning. Students demonstrated greater ability to analyze physiological data, interpret biomarker changes, and explain oxidative stress mechanisms using scientific evidence. Improvements were also observed in conceptual understanding and occupational health decision-making, indicating that Case-Based Learning facilitated both knowledge acquisition and the application of biomedical concepts in occupational health contexts.

Table 3. N-Gain Across Biomedical Literacy Dimensions

Dimension	Experimental	Control
Conceptual Understanding	0.63	0.34
Biomedical Data Interpretation	0.71	0.37
Scientific Reasoning	0.69	0.33
Occupational Health Decision-Making	0.58	0.35

Students' Biomedical Reasoning and Occupational Health Awareness

Classroom observations revealed that students in the experimental group demonstrated higher participation, collaboration, and engagement throughout the learning process. Students actively discussed biomedical cases, exchanged scientific arguments, and collaboratively interpreted physiological data related to oxidative stress.

Several students were able to explain the relationship between excessive physical activity, hypoxia, free radical formation, and oxidative stress mechanisms using scientific terminology accurately. Students also demonstrated improved awareness regarding occupational fatigue prevention strategies, including workload management, recovery periods, hydration, and maintaining physical fitness.

In contrast, students in the control group tended to focus primarily on memorizing concepts and showed limited ability to apply biomedical knowledge to occupational health situations. This finding suggests that Case-Based Learning fosters higher-order thinking skills by prompting students to analyze authentic problems and make evidence-based decisions.

The findings also suggest that integrating exercise physiology into occupational health education can bridge the gap between theoretical biomedical science and practical workplace health applications. Previous studies primarily focused on the physiological impacts of oxidative stress, whereas this study highlights the educational benefits of utilizing biomedical cases to strengthen occupational health literacy.

This finding is consistent with studies emphasizing the importance of contextualized biomedical education for developing evidence-based decision-making skills among health professionals. (Portela Dos Santos et al. 2022) reported that educational interventions grounded in authentic evidence can strengthen learners' ability to apply scientific knowledge in professional settings. Similarly, (Robertson et al. 2024) highlighted that biomedical literacy-oriented learning contributes to the development of higher-order thinking and graduate competencies in biomedical science curricula. In contrast to studies that focused primarily on evidence-based practice or assessment literacy, the present study demonstrates that occupational health biomedical literacy can also be strengthened through the integration of exercise-induced oxidative stress cases, thereby providing a novel educational context for Occupational Health and Safety programs.

To provide a clearer understanding of how Case-Based Learning (CBL) enhanced students' occupational health biomedical literacy, Figure 1 presents a conceptual summary of the main findings and discussion of this study. The figure illustrates the instructional mechanisms through which contextual biomedical cases related to exercise-induced oxidative stress improved students' abilities in data interpretation, scientific reasoning, occupational health awareness, and evidence-based decision-making. The illustration also highlights the relationship between authentic biomedical learning experiences and the development of higher biomedical literacy among Occupational Health and Safety students.

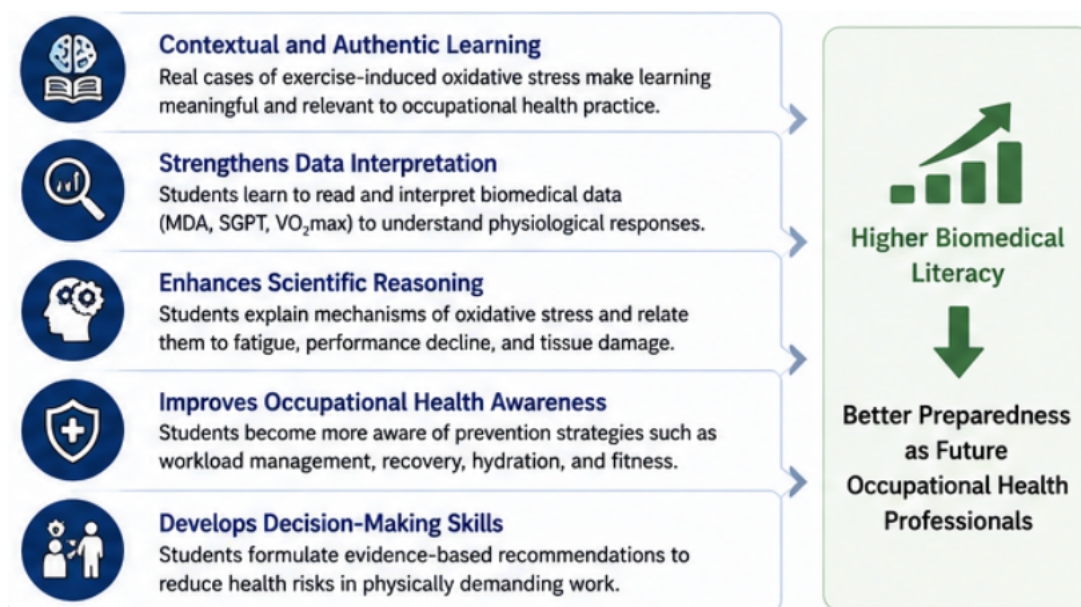


Figure 1. The Role of Case-Based Learning in Enhancing Occupational Health Biomedical Literacy

Figure 1 illustrates the conceptual mechanism explaining why Case-Based Learning (CBL) effectively improved occupational health biomedical literacy among students. The figure demonstrates that authentic and contextual biomedical learning experiences encourage students to actively construct scientific understanding rather than merely memorize theoretical concepts.

The first component, *Contextual and Authentic Learning*, explains that real biomedical cases related to exercise-induced oxidative stress made learning more meaningful and relevant to occupational health contexts. Students analyzed authentic physiological phenomena such as increased Malondialdehyde (MDA), Serum Glutamic Pyruvic Transaminase (SGPT), and decreased VO₂max associated with excessive physical activity. These biomedical indicators were adapted from previous physiological studies on oxidative stress during cycling activities.

The second component, *Strengthens Data Interpretation*, indicates that students developed the ability to interpret biomedical evidence, including biomarker changes and physiological responses associated with oxidative stress. Through biomedical case analysis, students learned how increased oxygen consumption during intense physical activity could trigger reactive oxygen species (ROS) production, lipid peroxidation, and tissue damage. This finding aligns with previous studies showing that elevated MDA and SGPT levels are indicators of oxidative stress and cellular injury after prolonged exercise.

The third component, *Enhances Scientific Reasoning*, demonstrates that students were able to explain physiological mechanisms underlying oxidative stress, fatigue, tissue damage, and performance decline using scientific arguments. The active discussion and collaborative problem-solving process encouraged students to connect biomedical concepts with occupational health risks in physically demanding work environments.

Furthermore, the figure shows that CBL improved *Occupational Health Awareness* by increasing students' understanding of preventive strategies such as workload management, hydration, recovery periods, and physical fitness maintenance. Students became more aware

that excessive physical activity and inadequate recovery may contribute to physiological stress and workplace health problems. The final component, *Develops Decision-Making Skills*, emphasizes that students could formulate evidence-based occupational health recommendations based on biomedical data analysis. This competency is important for future Occupational Health and Safety professionals who are required to make informed decisions regarding worker health and physiological risk prevention.

The contribution of this study lies in demonstrating that authentic biomedical cases derived from exercise physiology can serve as an effective educational medium for improving occupational health biomedical literacy. While previous studies have primarily focused on physiological outcomes of oxidative stress or the general effectiveness of Case-Based Learning, the present study integrates these domains and provides evidence that contextual biomedical case analysis can strengthen students' scientific reasoning, data interpretation, and occupational health decision-making skills. This contribution broadens the scope of biomedical literacy research and highlights its relevance within Occupational Health and Safety education.

CONCLUSION

This study demonstrated that Case-Based Learning (CBL) significantly improved occupational health biomedical literacy among Occupational Health and Safety (OHS) students compared to conventional lecture-based instruction. Students who participated in CBL achieved higher posttest scores and normalized gain values, indicating greater improvement in conceptual understanding, biomedical data interpretation, scientific reasoning, and occupational health decision-making skills related to exercise-induced oxidative stress.

The findings highlight the effectiveness of integrating authentic biomedical cases involving physiological indicators such as Malondialdehyde (MDA), Serum Glutamic Pyruvic Transaminase (SGPT), and $VO_2\text{max}$ into occupational health education. By connecting biomedical concepts with real-world occupational health problems, CBL facilitated meaningful learning experiences and strengthened students' ability to apply scientific evidence in occupational health contexts.

This study contributes to the growing body of research on contextual biomedical education by demonstrating that authentic case-based learning can be an effective strategy for enhancing biomedical literacy in Occupational Health and Safety programs. The integration of exercise-induced oxidative stress cases represents a novel educational approach that bridges biomedical science and occupational health practice.

Despite these contributions, this study was limited by the relatively small sample size and short intervention duration. Future research is recommended to involve larger samples, longer intervention periods, and technology-enhanced learning environments to further investigate the effectiveness of Case-Based Learning in occupational health education.

AUTHOR STATEMENTS

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This research received no external funding and was conducted independently by the authors.

Author Contributions

The first author conceptualized the study, designed the research methodology, developed the learning intervention, collected and analyzed the data, interpreted the findings, and prepared the original manuscript draft. The second author contributed to the research design, supervised the study, validated the research instruments, and critically reviewed the manuscript. The third author participated in data interpretation, provided expertise in occupational health and biomedical sciences, and contributed to manuscript revision. The fourth author assisted in data collection, statistical analysis, and interpretation of the results, while also reviewing the manuscript for important intellectual content. The fifth author supervised the overall research process, provided academic guidance throughout the study, critically revised the manuscript, and approved the final version for publication. All authors have read and approved the final manuscript and agree to be accountable for all aspects of the work.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

Data Availability Statement

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Ethical Approval

This study was conducted in accordance with the ethical principles for research involving human participants. All participants voluntarily agreed to participate and provided informed consent prior to data collection. Participant confidentiality and anonymity were maintained throughout the study.

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