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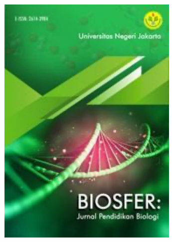

Citizen science learning in human anatomy and physiology education: a design-based approach

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ABSTRACT

Occupational Safety and Health (OSH) education requires instructional approaches that integrate scientific understanding with collaborative and contextual learning experiences. However, anatomy and physiology courses are often disconnected from authentic occupational health problems. The present research aimed to design and validate a Citizen Science Project (CSP) learning model for human anatomy and physiology education within occupational health contexts through a design-based research (DBR) approach. The study involved iterative stages consisting of needs analysis, model design, expert validation, implementation, and evaluation. Collaborative competence was positioned as the primary learning outcome and assessed through structured classroom observations involving undergraduate OSH students. The CSP model integrated five learning stages: mapping, project design, presentation, execution, and gallery walk activities. The findings showed that students demonstrated consistently high collaborative competence across instructional meetings, with mean scores ranging from 81.67 to 85.31 and an overall average of 82.28. Improvements were particularly observed during project execution and reflective dissemination activities. The results indicate that the CSP model effectively promotes collaborative learning and authentic inquiry in biology education. These findings contribute to the development of contextual and participatory instructional models that support collaborative competence in occupational health learning.

INTRODUCTION

Occupational Safety and Health (OSH) education plays a crucial role in preparing students to identify workplace hazards, interpret biological risk factors, and develop preventive strategies in professional environments (Li, 2025; Rankin, 2024). In anatomy and physiology courses, students are expected to connect biological concepts with authentic occupational health contexts. However, instructional practices in OSH education often remain theoretical and classroom-centered, limiting students' ability to relate scientific knowledge to real workplace situations (Adams & Dewsbury, 2022; Karanikas & Zerguine, 2025).

The disconnection between biological knowledge and occupational health practice creates challenges for students in interpreting workplace health evidence and making collaborative decisions in multidisciplinary contexts (Jen et al., 2015; Nobrega & Zhang, 2024). Modern workplaces increasingly demand collaborative competence, communication skills, and contextual problem-solving abilities among health professionals (Asino et al., 2022; Gallagher et al., 2025). Nevertheless, many instructional approaches in OSH education still emphasize individual learning and passive knowledge transmission, reducing opportunities for authentic inquiry and collaborative engagement.

Recent studies have highlighted the potential of Citizen Science Projects (CSP) as participatory and inquiry-oriented learning approaches that promote engagement, contextual understanding, and collaborative learning (Lüsse et al., 2022; Susiati, Bahri, et al., 2025). In educational settings, CSP has been widely implemented in environmental education, ecology, and public health learning to encourage active student participation in solving real-world problems (Kaarsted et al., 2023; Wiggins & Wilbanks, 2019). Previous findings indicate that CSP can improve scientific literacy, reflective learning, and community-based pproblem-solvingacross interdisciplinary educational contexts.

In the context of urban biology education, learning is increasingly expected to connect biological concepts with issues emerging from students' everyday environments and sociocultural experiences. Urban communities face diverse biological and public health challenges, including occupational exposure, environmental pollution, waste management, and lifestyle-related health risks. These issues provide meaningful contexts for developing scientific literacy and participatory inquiry among university students. Studies in urban biology education have emphasized the importance of contextual learning experiences that integrate local culture, community engagement, and real-world problem-solving to enhance students' understanding of biological phenomena and their societal implications (Aronson et al., 2017; Krasny & Tidball, 2020). Therefore, integrating citizen science into anatomy and physiology learning may offer students opportunities to investigate authentic health-related issues in their urban communities while strengthening collaborative and inquiry-based competencies.

Despite its educational potential, the application of CSP in occupational health education and urban biology learning contexts remains limited, particularly in higher education settings where anatomy and physiology concepts are expected to be connected with authentic community-based health issues (Hardjo et al., 2025). Furthermore, few studies have systematically designed and validated CSP-based instructional models specifically aimed at developing collaborative competence in occupational health contexts. Therefore, this research offers a novel contribution by developing a citizen science project learning model that integrates authentic occupational health issues, participatory inquiry, collaborative learning processes, and urban community contexts within human anatomy and physiology education.

Using a design-based research (DBR) approach, this study aims to design and validate a citizen science project learning model for anatomy and physiology courses in occupational health education. The study focuses on developing an instructional framework that supports collaborative competence through authentic, inquiry-based, and context-oriented learning experiences.

METHODS

Research Design

This study employed a design-based research (DBR) approach to design and validate a citizen science project (CSP) learning model for human anatomy and physiology education in occupational health contexts. DBR was selected because it facilitates iterative development, refinement, and evaluation of instructional interventions in authentic educational settings while generating transferable pedagogical knowledge (Plomp & Nieveen, 2013). Collaborative competence was positioned as the primary instructional outcome guiding the development and validation of the model.

Population and Samples

The population of this study consisted of undergraduate students enrolled in the Occupational Safety and Health (OSH) program at a higher education institution. Purposive sampling was employed to select one intact class consisting of 40 students enrolled in a human anatomy and physiology course. The participants were selected because the course content aligned with the CSP learning model's contextual objectives. The study was conducted from September to November 2025. Participant demographic characteristics are presented in Table 1.

Table 1
Demographic Characteristics of Participants

Variable	Category	Frequency	Percentage
Gender	Male	14	35%
	Female	26	65%
Age	18–20 years	28	70%
	21–23 years	12	30%
Academic Year	Second Year	40	100%

Instrument

Data collection focused on assessing students' collaborative competence during the implementation of the Citizen Science Project (CSP) learning model. Collaborative competence was measured using a structured observation instrument adapted from collaborative learning frameworks proposed by Johnson and Johnson and further developed in higher education collaboration studies (Fernandes Agreli et al., 2021; Johnson & Johnson, 2002). The instrument was designed to capture observable collaborative behaviors demonstrated during learning activities.

The observation instrument consisted of five dimensions of collaborative competence: shared responsibility, communication, coordination, participation, and mutual support. Shared responsibility refers to students' commitment to accomplishing group tasks collectively. Communication reflects the effectiveness of exchanging ideas and information among group members. Coordination measures students' ability to organize tasks and synchronize activities. Participation is assessed by the extent of active involvement in group discussions and project implementation. Mutual support examines students' willingness to assist peers and contribute to collective problem-solving. Each indicator was assessed on a 4-point scale from 1 (very low) to 4 (very high). Scores were recorded during classroom observations throughout the implementation of CSP activities and subsequently converted into percentage values to facilitate the interpretation of collaborative competence levels.

Procedure

The research procedure followed the iterative DBR cycle adapted from Plomp & Nieveen (2013). The study began with a preliminary analysis to identify instructional problems and learning needs in anatomy and physiology courses. The second phase involved designing and developing the CSP learning model and its supporting instruments. The third phase focused on classroom implementation of the developed model. Finally, evaluation and reflection were conducted to examine collaborative competence outcomes and refine the instructional model based on expert and implementation feedback. The research procedure followed four DBR phases: (1) preliminary analysis, (2) design and prototyping, (3) implementation, and (4) evaluation and reflection. During the preliminary phase, literature analysis and contextual investigations were conducted to identify instructional needs in anatomy and physiology courses for OSH students. The design phase focused on constructing the CSP learning syntax, learning activities, and assessment instruments. The implementation phase involved classroom application of the developed model, while the evaluation phase examined collaborative competence outcomes and expert feedback to refine the instructional design.

The overall stages of the design-based research process implemented in this study are illustrated in Figure 1. The procedure consisted of four iterative phases: preliminary analysis, design and prototyping, implementation, and evaluation-reflection. Each phase informed subsequent refinements of the CSP learning model.

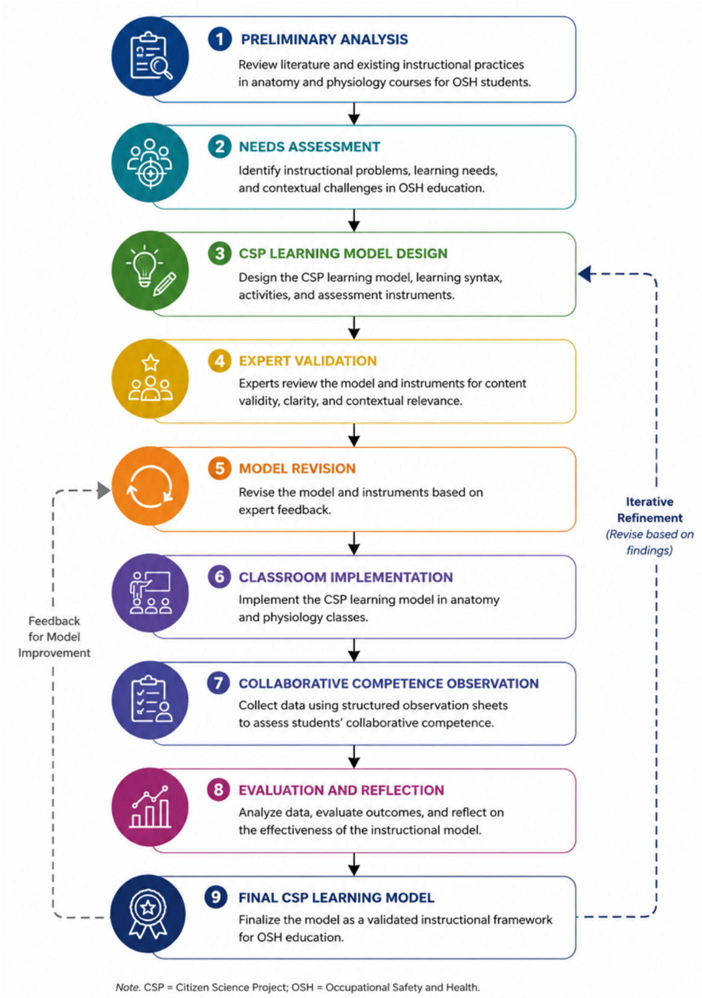

Figure 1. Design-Based Research Procedure of the CSP Learning Model.

Data Analysis Techniques

Quantitative descriptive analysis was employed to examine students' collaborative competence during the implementation of the CSP learning model. Mean scores and percentage values were calculated for each collaborative competence dimension to identify patterns of student engagement across learning sessions. Descriptive statistics were used to determine the level and progression of collaborative competence throughout the intervention.

Observational field notes collected during classroom activities were analyzed to support interpretation of quantitative findings and provide contextual explanations of collaborative behaviors. Triangulation between observation scores and field notes enhanced the credibility of the findings. The results were subsequently used to evaluate the effectiveness of the CSP learning model and inform further model refinement.

RESULTS AND DISCUSSION

The design-based research process generated a validated citizen science project (CSP) learning model for human anatomy and physiology education in occupational safety and health (OSH) programs. Beyond improving students' collaborative competence, the study produced a set of transferable design principles that explain how citizen science activities can facilitate contextual understanding, authentic inquiry, and collaborative engagement. These findings contribute to the growing body of research on citizen science in higher education by extending its application to occupational health-oriented anatomy and physiology learning, an area that remains underexplored in previous studies.

The CSP Learning Model for Occupational Health Education

The DBR process resulted in the development of a CSP learning model tailored for human anatomy and physiology courses in OSH programs. The model was developed to respond to students' persistent difficulty in comprehending abstract biological concepts and the limited opportunities for meaningful collaborative engagement within conventional instructional approaches (Susiati, Bahri, et al., 2025).

The CSP learning model is structured into five sequential learning stages: mapping, project design, presenting, execution, and gallery walk. These stages guide students from initial conceptual engagement toward collaborative inquiry and reflective dissemination of findings. The structure reflects professional occupational health practices, in which scientific understanding, teamwork, and contextual problem-solving are closely integrated (Susiati, Azis, et al., 2025).

Novel Contributions of the CSP Learning Model

The primary contribution of this study extends beyond the development of a new instructional sequence. The DBR process generated a theoretically grounded instructional model that integrates citizen science principles with occupational health-oriented anatomy and physiology learning. Previous citizen science studies have predominantly focused on environmental education, ecological monitoring, and public health campaigns (Bonney et al., 2016; Kaarsted et al., 2023). In contrast, the present model demonstrates how citizen science can be adapted to support the development of collaborative competence in professional health education contexts.

Three novel design contributions emerged from the study. First, authentic workplace health issues were used as inquiry triggers that connected biological concepts with students' future professional responsibilities. Second, participatory investigation activities enabled students to collaboratively generate and interpret health-related evidence. Third, reflective dissemination through gallery walk sessions strengthened scientific communication and collective knowledge construction. Together, these design principles provide a transferable framework for contextual biology education in applied health science programs.

Design Principles of the CSP Learning Model

The DBR process further generated a set of design principles that explain how and why the CSP learning model supports collaborative learning in occupational health education. These principles were synthesized through iterative design, expert validation, and classroom implementation. Rather than describing procedural steps, the principles articulate transferable pedagogical logic that can inform similar implementations in applied health science education.

Table 2
Design Principles of the CSP Learning Model for Occupational Health Education

Design Principle	Operational Description	Theoretical & Pedagogical Basis	Expected Learning Outcomes
Authentic Occupational Health Context	Learning activities are grounded in real occupational health and safety issues related to human anatomy and physiology (ergonomic risks, musculoskeletal strain, physiological responses to exposure).	Meaningful learning; contextual learning (David P. Ausubel, 1963); applied health science education	Improved relevance of anatomical knowledge and ability to apply concepts to workplace risk analysis
Participatory Citizen Science Inquiry	Students actively participate in identifying problems, collecting field data, and interpreting findings using citizen science approaches.	Constructivist learning (Brau, 2020); inquiry-based learning (Sordé Martí et al., 2020); citizen science pedagogy	Enhanced scientific literacy and understanding of scientific practices
Collaborative Project-Based Structure	Learning tasks require shared planning, role distribution, joint decision-making, and collective responsibility within student groups.	Social constructivism (Y. Kim, 2024); collaborative learning theory (Ofstedal & Dahlberg, 2009a)	Development of collaborative competence essential for OSH professional practice
Progressive Learning Syntax	Learning progresses through structured stages: mapping, project design, presenting, execution, and gallery walk.	Project based learning (Greenstein, 2012); experiential learning cycle	Gradual development from conceptual understanding to applied and reflective learning

Design Principle	Operational Description	Theoretical & Pedagogical Basis	Expected Learning Outcomes
Iterative Feedback and Reflection	Peer and instructor feedback is embedded during presenting and gallery walk stages to refine projects and interpretations.	Reflective learning; formative assessment (Griggs et al., 2018)	Improved scientific reasoning, communication, and teamwork quality
Integration of Digital Learning Support	Learning management systems and digital tools support access to resources, communication, documentation, and reflection.	Blended learning; digital pedagogy (Kilipiris et al., 2024)	Flexible learning pathways and continuity between classroom and fieldwork
Contextualized Performance Assessment	Assessment focuses on scientific literacy, problem-solving, and collaboration demonstrated through project outputs and processes.	Authentic assessment; competency based evaluation	Alignment between learning objectives, activities, and assessment outcomes

As presented in Table 2, the CSP learning model emphasizes authentic occupational health contexts, participatory inquiry, collaborative project-based learning, and reflective practices as central instructional components. These principles position students as active participants in investigating workplace-related biological issues while collaboratively constructing scientific understanding through inquiry and field-oriented activities. The integration of iterative feedback mechanisms and digital learning support further strengthens reflective engagement and continuous learning improvement.

The theoretical foundations underlying the model indicate that the CSP framework is strongly aligned with constructivist, inquiry-based, and experiential learning perspectives. Furthermore, the expected learning outcomes demonstrate that the model is designed not only to improve scientific understanding in anatomy and physiology but also to enhance collaborative competence, communication skills, problem-solving abilities, and contextual application of occupational health knowledge.

The design principles emphasize authenticity, participatory inquiry, structured collaboration, and reflective learning as foundational elements of the CSP model. Together, these principles form a coherent instructional framework that positions collaboration as an intentional and designable learning outcome. The design-based research process resulted in the development of a Citizen Science Project (CSP) learning model for occupational health education. The conceptual framework of the model, illustrating the relationship between design principles, learning stages, and collaborative competence as the primary design outcome.

To provide a clearer conceptual representation of the developed instructional framework, Figure 2 illustrates the overall structure of the CSP learning model. The figure demonstrates the relationship between instructional principles, learning stages, collaborative competence development, and expected learning outcomes within occupational health education contexts.

The CSP learning model is structured as an integrated instructional framework connecting authentic inquiry activities with collaborative learning processes. The model begins with contextual problem identification and progresses through participatory investigation, project implementation, reflection, and evaluation stages. Throughout these stages, collaborative competence is continuously developed through communication, shared responsibility, coordination, and reflective interaction among students. The iterative nature of the CSP framework, where feedback and reflection function as mechanisms for instructional refinement and deeper conceptual understanding. This structure supports the development of meaningful learning experiences that align biological knowledge with authentic occupational health practices.

Building on these principles, the CSP learning model is operationalized through five sequential learning stages: mapping, project design, presenting, execution, and gallery walk. The mapping stage supports initial conceptual understanding of anatomy and physiology in relation to occupational health risks (Buzan, 2018). The project design stage emphasizes collaborative problem formulation and shared planning. The presenting stage functions as a formative feedback mechanism, enabling peer and instructor input. The execution stage involves participatory data collection and analysis in authentic contexts, while the gallery walk stage facilitates dissemination, peer evaluation, and collective reflection (Susiati et al., 2025).

The framework culminates in collaborative competence as the primary learning outcome, supported across all stages of the learning process. Rather than emerging incidentally, collaboration is embedded through shared responsibility, coordinated inquiry, and reflective interaction (Paiva et al., 2020). The cyclical nature of the framework indicates that learning outcomes inform ongoing refinement of instructional design, consistent with the principles of design-based research.

Students' Collaborative Competence during CSP Implementation

Empirical evidence of the CSP learning model's functionality was examined through students' collaborative competence, which served as the primary design outcome of this study. Collaborative competence was observed across seven instructional meetings during the implementation of the CSP learning model.

To examine the effectiveness of the CSP learning model during implementation, students' collaborative competence was observed across seven instructional meetings. The observation focused on students' communication, participation, shared responsibility, and coordination during collaborative inquiry and project-based learning activities. The mean scores of collaborative competence across instructional meetings are presented in Table 3.

Table 3
Mean Scores of Students' Collaborative Competence Across CSP Learning Sessions

Meetings	Learning Material	Mean ± SD
Meetings 1	Introduction to Human Anatomy, CSP Orientation, group formation	81.67 ± 4.12
Meetings 2	Musculoskeletal System	81.98 ± 3.95
Meetings 3	Nervous System	81.98 ± 3.84
Meetings 4	Nervous System	82.19 ± 3.62
Meetings 5	Respiratory System	82.60 ± 3.41
Meetings 6	Digestive System	83.23 ± 3.18
Meetings 7	Integration of Body Systems and Citizen Science Project Presentation	85.31 ± 2.97
Average		82.28 ± 3.58

As shown in Table 3, students demonstrated consistently high levels of collaborative competence throughout the implementation of the CSP learning model. Mean scores ranged from 81.67 to 85.31, the gradual increase in collaborative competence scores suggests that repeated engagement in citizen science inquiry promoted sustained interaction among group members. This finding aligns with Social Constructivist Theory, which posits that collaborative knowledge construction emerges through participation in shared activities and dialogue. Similar improvements have been reported in citizen science and project-based learning studies that emphasize authentic problem solving and collective investigation (Bonney et al., 2016; Gallagher et al., 2025).

During the initial meetings (Meetings 1–3), collaborative competence scores remained relatively stable, suggesting that students were adapting to the participatory inquiry structure and collaborative learning environment introduced by the CSP model. A gradual increase in collaborative competence was observed beginning in Meeting 4, indicating stronger engagement in group coordination, communication, and shared problem-solving activities.

The highest collaborative competence score was recorded in Meeting 7 (85.31), coinciding with learning activities emphasizing project implementation, presentation, and reflective discussion. These activities required students to actively negotiate ideas, distribute responsibilities, and collaboratively interpret occupational health problems. The upward trend observed across instructional meetings suggests that collaborative competence was not incidental but intentionally facilitated through the structured syntax of the CSP learning model.

These findings support constructivist and collaborative learning perspectives, which emphasize that meaningful interaction, inquiry participation, and reflective engagement contribute significantly to the development of collaborative competence in authentic learning environments (Ofstedal & Dahlberg, 2009). The results also indicate that the CSP model successfully positioned collaboration as a measurable instructional outcome within occupational health education contexts.

The alignment between the CSP learning model's design principles and the observed development of collaborative competence suggests that collaboration was intentionally fostered through model structure and learning syntax. The following discussion interprets these results by examining how participatory inquiry, authentic occupational health contexts, and structured collaboration contributed to collaboration as a design outcome within a design-based research framework. The following discussion further interprets these findings by examining how the instructional characteristics of the CSP learning model contributed to the development of collaborative competence within authentic occupational health learning contexts.

Student Reflections

Classroom observations revealed substantial improvements in student interaction quality during the implementation phase. During the initial meetings, students tended to divide tasks individually with limited discussion. However, by the project execution and gallery walk stages, students increasingly engaged in collaborative problem solving, evidence-based discussion, and peer feedback activities.
One student noted:

> *"The project helped us understand how anatomy and physiology concepts relate to real workplace health issues. We learned more through discussion and field investigation than through conventional lectures."*

These findings support social constructivist perspectives, suggesting that knowledge develops through collaborative interaction and authentic participation in meaningful tasks. This study demonstrates that collaborative competence can be intentionally developed through instructional design grounded in citizen science, authentic inquiry, and participatory learning principles. The consistently high collaborative competence scores observed during implementation indicate that the CSP learning model successfully created a learning environment that encouraged communication, coordination, shared responsibility, and collective problem-solving among students. Rather than functioning merely as supplementary classroom activities, the collaborative processes embedded within the CSP framework became central mechanisms through which students constructed an understanding of occupational health issues.

The model's effectiveness can be explained by the interaction between authentic occupational health contexts and participatory inquiry activities. Authentic learning situations encouraged students to connect anatomical and physiological concepts with real workplace problems, thereby increasing the relevance and meaningfulness of learning experiences. According to constructivist learning perspectives, meaningful knowledge construction occurs when students actively engage with contextual problems and collaboratively negotiate understanding through social interaction (Brau, 2020; Kim, 2024). This explains why collaborative competence progressively increased as students became more engaged in inquiry-based project activities throughout the instructional meetings.

The gradual increase in collaborative competence across instructional meetings also suggests that collaboration developed cumulatively through repeated participatory interactions. The structured learning syntax, consisting of mapping, project design, presenting, execution, and gallery walk stages, provided iterative opportunities for students to negotiate roles, exchange perspectives, and refine their collective understanding. This finding aligns with experiential learning theory, which emphasizes that competence develops through continuous cycles of action, reflection, feedback, and reconstruction of experience (Greenstein, 2012). In the context of occupational health education, such iterative collaboration is particularly important because professional practice requires multidisciplinary communication and coordinated decision-making in dynamic workplace environments (Susiati et al., 2025).

The presenting and gallery walk stages appeared to play a particularly significant role in strengthening collaborative competence. These stages required students not only to communicate project findings but also to critically evaluate peer interpretations and respond to feedback through reflective dialogue. Such interaction-rich activities functioned as reflective social spaces that promoted accountability, mutual respect, and collaborative reasoning. Previous studies have similarly shown that reflective dissemination and peer evaluation processes contribute substantially to the quality of collaborative learning and to scientific communication competence (Griggs et al., 2018; Paiva et al., 2020). Therefore, the increase in collaborative competence observed in later instructional meetings may reflect students' growing confidence and familiarity with collaborative inquiry practices embedded within the CSP model.

The sustained collaborative engagement observed during the execution stage also highlights the role of structured collaboration supported by digital learning environments (Table 1). Despite the inherent complexity of field-based citizen science activities, students maintained high levels of collaboration through coordinated role distribution and shared responsibility. This finding suggests that the CSP learning model provides sufficient structural scaffolding to support collaboration even in less predictable learning contexts, reinforcing its practical applicability in occupational health education (Tinoca et al., 2022).

From a design-based research perspective, these findings contribute to instructional design theory by demonstrating how collaborative competence can be deliberately designed rather than assumed. The CSP learning model integrates collaboration into its pedagogical logic through authentic inquiry, participatory problem-solving, and reflective dissemination, as articulated in the design principles (Table 1). The empirical patterns observed in collaborative competence (Table 2) provide evidence that these principles functioned as intended within the learning environment.

From a design-based research perspective, this study contributes to instructional design theory by demonstrating that collaborative competence can function as an intentionally designed pedagogical outcome rather than an incidental byproduct of group work. The CSP learning model operationalizes collaboration through contextual inquiry, participatory investigation, structured interaction, and reflective dissemination, which systematically support collaborative engagement. The findings, therefore, extend previous citizen science education studies, which have primarily emphasized scientific literacy and participation outcomes, by showing that citizen science pedagogies can also strengthen collaborative competence within applied professional education contexts.

CONCLUSION

This study developed and validated a citizen science project (CSP) learning model for occupational health education using a design-based research approach, with collaborative competence positioned as the primary instructional outcome. The findings demonstrated that the CSP learning model effectively fostered collaborative competence through authentic occupational health contexts, participatory inquiry, structured project-based activities, and reflective learning processes. The progressively increasing collaborative competence scores observed across instructional meetings indicate that collaboration was intentionally embedded within the instructional design rather than emerging incidentally during learning activities. The integration of contextual inquiry, collaborative investigation, and reflective dissemination enabled students to actively engage in communication, coordination, shared responsibility, and problem-solving related to occupational health issues. These findings imply that citizen science–based pedagogies can provide a practical and transferable instructional framework for strengthening collaborative competence in Biology Education and applied health science learning. This study also contributes to instructional design theory by demonstrating how collaborative competence can be systematically designed and implemented through participatory and context-oriented learning environments in occupational health education.

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