Measuring Perceived Research Proficiency among Puerto Rican Middle Schoolers using Macroinvertebrates-Based Learning Interventions

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Abstract

This action research investigated the development of scientific research competencies and ecological awareness among sixth- and seventh-grade students through Macroinvertebrates-Based Learning Interventions (MBLI). Conducted at a bilingual private school in the San Juan metropolitan area, the study addressed three key challenges: limited research skills, low confidence in conducting scientific analyses, and difficulty connecting theoretical knowledge to real-world ecological contexts. MBLI, a structured sequence of experiential, hands-on learning activities centered on the study of aquatic macroinvertebrates, was designed to foster inquiry, observation, and environmental literacy.

The objectives were to assess students' initial levels of scientific competence and ecological awareness, implement a targeted skill-development intervention—focusing on observation, classification, measurement, data collection and analysis, collaboration, and communication—and evaluate changes post-intervention. A quantitative methodology was used, including the design and administration of pre- and post-tests, as well as educational modules and activity worksheets. In total, 57 students participated—36 females and 21 males. Most completed the intervention successfully, reflecting strong engagement.

Results revealed a significant increase in content knowledge, with a large effect size ($d = -2.619$), demonstrating the intervention's effectiveness. While attitudinal measures remained stable, ecological awareness increased moderately ($p = .006$; $d = -0.431$), indicating meaningful, though less pronounced, gains. Students showed notable improvement in research skills and confidence in applying scientific methods to real-world ecological problems. These findings underscore the value of MBLI and hands-on, inquiry-based learning strategies in bridging gaps in research proficiency and ecological awareness, ultimately contributing to enhanced science education outcomes.

Introduction

In an era where scientific literacy and ecological stewardship are gaining increasing importance, there is a growing demand for innovative educational strategies that cultivate both research skills and environmental consciousness among students. This study explored the design, implementation, and evaluation of Macroinvertebrate-Based Learning Interventions (MBLI) to enhance students' research proficiency and ecological awareness. MBLI, is a concept introduced by the researcher, and refers to a structured sequence of experiential, hands-on learning activities centered around the study of macroinvertebrates. These interventions were designed to foster students' ability to engage in scientific inquiry while deepening their understanding of ecological systems. The core concept research competencies, research proficiency, ecological awareness, and MBLI were integrated within the broader framework of science education to support the development of scientifically informed and environmentally responsible learners.

Research competencies are the skills that researchers develop to effectively conduct, engage and contribute to the scientific inquiry process. The skills include observation, classification, performing basic measurements, handling instrumentation, as well as, collecting, organizing, and analyzing data with emphasis in teamwork and the development of communication skills. This leads to the concept of research proficiency, which refers to the level of mastery of these competencies. Research competencies are crucial for academic success in terms of proficiency, as they enable students to learn, identify, engage, and argument new knowledge (Castillo-Martinez & Soledad, 2021; Van de Wetering, et. al., 2022). A lack on the previously mentioned competencies hinders the ability to understand, relate and address complex environmental issues, resulting in a failure to foster ecological awareness among students.

Students do not have an innate instinct to relate and interact with nature (Božak, et. al., 2023). It is necessary to teach them the importance of that interaction, and its relevance to ignite ecological awareness. Ecological awareness is a competency that provides knowledge about the environment, the connection with people, as well as the capacity to identify and address environmental challenges. This concept represented a fundamental aspect to comprehend the relationship within ecosystems. A lack of ecological awareness can delay the student's ability to comprehend, attend and solve environmental problems. Recent studies (Marques & Xavier, 2020; Marpa, 2020; Dutta, 2024) stated that nurturing ecological awareness through environmental education is the most effective path to re-orient education.

One effective way to promote ecological awareness is through the study of macroinvertebrates. Macroinvertebrates are aquatic organisms that lack a backbone and serve as bioindicators because they are used to assess the health of an ecosystem. Macroinvertebrates-Based Learning is a pedagogical approach that incorporates aquatic organisms into educational activities to enhance students' understanding of ecological concepts and develop essential research competencies. This quantitative action research aimed to investigate the potential of Macroinvertebrates-Based Learning Interventions to address the identified gaps in research competencies, particularly ecological awareness.

Macroinvertebrate-Based Learning Interventions integrated the prior concepts into a coherent educational framework. They used the study of macroinvertebrates as a specific experiential learning tool to simultaneously build research proficiency and ecological awareness. Through activities such as sampling aquatic habitats, identifying species, and analyzing water quality, students actively apply scientific methods and deepen their understanding of ecological principles. Recent studies (Kong, 2021; Yao, 2023) stated that experiential learning is a pedagogical approach that emphasizes active, hands-on experiences to facilitate learning. It involves learners actively engaging with the world around them, reflecting on their experiences, and applying their new understanding to real-world situations. This approach is often contrasted with traditional methods that rely heavily on lectures and textbooks. This interconnected framework enhances students' ability to conduct scientific research and understand environmental issues, preparing them to become informed and engaged citizens capable of addressing complex ecological challenges.

The interventions consisted of a series of activities designed to develop specific skills and knowledge related to macroinvertebrates, water quality, and research methodologies. These activities included macroinvertebrates field sampling and identification, water quality testing, freshwater emerging disruptors, and teamwork-based experiment design. By integrating macroinvertebrates-based learning into educational activities, educators can enhance students' understanding of ecological concepts while simultaneously developing essential research competencies. This pedagogical approach enabled students to engage in hands-on investigations, fostering critical thinking and problem-solving skills essential for addressing environmental challenges. By participating in these interventions, students developed essential research competencies, enhanced their ecological awareness and gained valuable hands-on experience in scientific inquiry.

Theorists and experts on classroom science research have emphasized the importance of experiential learning in promoting student engagement, critical thinking, and problem-solving skills. Macroinvertebrates-Based Learning aligns with these principles by providing students with opportunities to explore natural environments, collect and analyze data, and work collaboratively to solve real-world problems. The importance of the action research that will be conducted lies in its potential to contribute to the development of innovative educational programs and curricula. By demonstrating the effectiveness of Macroinvertebrates-Based Learning in enhancing research competencies and ecological awareness, this study can inform future research and practice in science education.

Problem

Research competency is essential for students' academic and professional development. However, many middle school students lack the confidence and skills necessary to perform the analysis necessary to solve scientific problems effectively (Ayuso et al., 2022). In fact, as a result of this lack of skills, the connection between what has been learned and the impact that it can imply for society, such as ecological awareness, is difficult. The ecological awareness of macroinvertebrates in fresh water is a novel educational strategy to foster skills, abilities, sustainable and responsible behaviors which are crucial for young people. This study seeks to address quantitatively students' pre- and post-perception of educational interventions focused on the study of macroinvertebrates.

Specific Difficulties

The three specific challenges derived from the research problem are:

a. Lack of research skills and competencies: The absence of skills in areas such as observation, classification, measurement, data collection and analysis, as well as in collaborative work and effective communication, can hinder progress in the research project.

b. Lack of confidence in the ability to perform scientific analyses: Uncertainty regarding the ability to conduct scientific analyses can limit researchers' capacity to address complex problems and develop effective solutions.

c. Difficulty connecting learned concepts with practical applications: The inability to relate theoretical knowledge to practical applications, specifically ecological awareness.

Table 1. Specific difficulties

Specific Difficulties	Descriptions
Lack of Research Skills and Abilities	The absence of skills in areas such as observation, classification, measurement, data collection, and analysis, as well as in collaborative work and effective communication, can hinder progress in the research project.
Lack of Confidence in the Ability to Conduct Scientific Analysis	Insecurity about the ability to perform scientific analysis can limit researchers' capacity to address complex problems and develop effective solutions.

Specific Difficulties	Descriptions
Difficulty Connecting Learned Knowledge to Practical Applications	The inability to relate theoretical knowledge to practical applications can create challenges in translating academic learning into real-world use.

Objectives

This action research aims to:

- explore the level of scientific research competence among sixth and seventh-grade students in the Science course.
- implement an action plan emphasizing the connection between acquired knowledge and ecological awareness from an alternative perspective, focused on the development of skills (e.g., observation, classification, measurement, data collection and analysis, collaborative work, and effective communication).
- measure the change in the level of scientific research competence among students before and after the implementation of the action plan.
- rate the potential of Macroinvertebrates-Based Learning Interventions to address the identified gaps in research competencies, particularly ecological awareness.

Variables

A. **Independent variable**: Macroinvertebrates - Based Learning Interventions
    1. Various practical activities (collections and observation of macroinvertebrates, water quality testing, macroinvertebrates ecological roles, emerging stressors)

B. **Dependent variables**: Research competences and Ecological Consciousness
    1. Ecological Consciousness
        a. Level of knowledge about the ecological importance of macroinvertebrates
    2. Research Competences
        a. Skills in the design and execution of scientific research.
        b. Ability to formulate hypotheses and make precise observations.
        c. Analysis and presentation of research data.

d. Ability to work collaboratively on research projects.

C. **Controlled variables:** Demographic characteristics and Conditions of the Educational Environment

1. Demographic characteristics
   a. Grade of the students (6th and 7th grades – Transitional grades)
2. Conditions of the Educational Environment
   a. Resources and materials available for activities.
   b. Time dedicated to intervention activities (During the class period).

Scientific Questions

Based on the objectives, the following research questions were established. These questions facilitated the collection of data regarding the actions taken to address the specific difficulties identified as part of the research problem. The questions are as follows:

- What is the level of scientific research competence among sixth and seventh grade students?
- What is the level of ecological awareness among sixth and seventh grade students?
- How should an action plan be implemented with an emphasis on connecting acquired knowledge to environmental awareness from an alternative perspective, focusing on skill development (e.g., observation, classification, measurement, data collection and analysis, collaborative work, and effective communication)?
- How does the level of scientific research competence change among sixth and seventh grade students?
- How does the level of ecological awareness change among sixth and seventh grade students after the Macroinvertebrates-Based Learning Interventions?

Method

In this action research, quantitative methods were employed to guide the implementation of the action plan and the collection of data and information. Research using quantitative methods, according to Hernández et al. (2014), "relies on measurement (where the variables or concepts in the hypotheses are measured). This data collection was carried out using standardized procedures that are accepted by the scientific community" (p. 5). The authors emphasized that since the data comes from measurements, it is represented by numbers and analyzed through statistical methods.

According to Ghanad (2023) and Sharma, et. all. (2023), quantitative methods involve the systematic measurement of variables through statistical techniques, aiming to produce objective, reliable data. The use of quantitative methods was essential for this study, as it enabled the measurement of the level of scientific research competence among students, as well as the changes in this competence over time, particularly in relation to ecological awareness.

The primary objective of this research was to explore the level of scientific research competence among sixth and seventh-grade students in the Science course. This study also aimed to implement an action plan that emphasized the connection between acquired scientific knowledge and ecological awareness, with a focus on developing key skills such as observation, classification, measurement, data collection and analysis, collaborative work, and effective communication. Through the execution of this plan, the study sought to measure changes in students' scientific research competence before and after the intervention. Additionally, it assessed the potential of Macroinvertebrate-Based Learning Interventions to address identified gaps in research competencies, particularly in the area of ecological awareness.

The quantitative approach allowed for precise measurement of these variables individually, providing a reliable description of the relationship between the research components. To accomplish this, pre- and post-tests focused on thematic content and activities related to macroinvertebrates and ecological awareness were administered. This methodology allowed for an accurate assessment of students' knowledge and skills before and after the intervention, yielding clear data on the impact of the implemented action plan.

This approach contributed to understanding the complexities of the issue, providing valuable insights that can inform the literature and offer potential solutions for improving academic processes and student outcomes. By measuring these variables quantitatively, this research delivered a reliable description of the students' experiences with the proposed ecological concepts in Puerto Rico, ensuring that the results are both objective and meaningful.

The quantitative phase of the study involved the conceptualization and development of both pre- and post-tests, the design of a teaching module for educators and students, and the administration of Macroinvertebrate-Based Learning Intervention worksheets. These tools were intended to investigate students' understanding of and engagement with ecological topics. In line with Kline (1993) and the *Standards for Educational and Psychological Testing* (2014), quantitative research employs measurement instruments to describe reality as objectively as possible, assigning measurable attributes to both individual and group variables. By employing these instruments, the study aimed to offer a clear, evidence-based understanding of how students' research competencies and ecological awareness evolved over the course of the intervention.

Design

Action research design is particularly beneficial in science education as it focuses on addressing real-world problems through a cyclical process of planning, action, observation, and reflection (Baum, Mac Dougall & Smith, 2006). Action research is "any research conducted by teacher-researchers, principals, school counselors, or anyone interested in the area of teaching/learning, aimed at gathering information about how work is carried out in their respective schools, how they teach, or how students learn" (Mills, 2018, p. 5). This model emphasizes active teacher engagement in the research process to improve teaching practices continuously. The action research design was chosen for this study because it allows for iterative improvements in response to emerging challenges, which is especially relevant in dynamic science classrooms. Educators can experiment with various teaching strategies, assess their effectiveness, and refine their methods based on direct feedback and data, ensuring that the learning experience is both effective and aligned with student needs.

In the context of science education, action research can be applied in various ways to enhance both conceptual understanding and the development of scientific competencies. For example, a teacher might investigate how different methods, such as inquiry-based learning or the use of technology in experiments, influence students' comprehension of concepts like ecosystems or chemical reactions. Action research can also focus on improving practical skills, such as data collection, experimental design, or scientific communication. This approach allows teachers to tailor their methods to address specific gaps in students' understanding, ensuring that the curriculum not only covers scientific content but also fosters critical thinking and problem-solving skills that are essential in science.

The importance of action research in addressing both science conceptualizations and competencies cannot be overstated. Conceptual understanding refers to grasping key scientific principles, while competencies involve the ability to apply those concepts in real-world situations. Action research enables teachers to assess how well students are acquiring both aspects, adjusting their teaching methods based on real-time feedback. For instance, if students struggle to connect theoretical concepts with practical applications, the teacher can experiment with new strategies such as hands-on activities or project-based learning. This process of reflection and adaptation is crucial for helping students develop both a deep understanding of scientific concepts and the practical skills to apply them effectively.

The benefits of using action research in science education are numerous (Kinskey, 2018). First, it leads to improved teaching practices. Teachers can experiment with new instructional strategies, assess their effectiveness, and refine their methods, which leads to more engaging and effective lessons. Additionally, action research fosters a student-centered learning environment by providing teachers with insights into students' needs and learning styles, allowing them to adjust their teaching accordingly. This approach also enhances scientific competencies by engaging students in inquiry and problem-solving, helping them develop essential skills such as data collection, analysis, and communication. Furthermore, action research supports continuous professional growth for educators. By reflecting on and adjusting their teaching practices, teachers become more effective in their roles. Finally, action research promotes evidence-based decision-making. Teachers can use data collected from their own classrooms to make informed decisions about teaching methods, curriculum changes, and student support, ensuring that their strategies are based on actual student performance and learning outcomes.

In brief, action research design is a powerful tool for improving science education. It allows teachers to refine their practices continuously, create more engaging and effective lessons, and ensure that students develop both a solid understanding of scientific concepts and the necessary competencies to apply them. By adopting this approach, educators can provide more dynamic, student-centered learning experiences that promote critical thinking and scientific inquiry, ultimately preparing students for success in the sciences.

Action Research Model

Mills (2018) emphasized that the research is conducted by the teachers themselves; it is not imposed on them. Creswell and Guetterman (2019) stated that action research "is a useful design for addressing specific classroom problems and for strengthening individuals to improve their work situations" (p. 587). They added that "educators aim to improve educational practice by studying an issue or problem they face. Educators reflect on these problems, collect and analyze data, and implement changes based on their findings" (p. 587).

To implement the action, the model of John Elliott (1987) was chosen. This model emphasizes reflective practice and inquiry-based learning, making it particularly well-suited for fostering both research skills and ecological awareness in a science classroom. The model was selected because it encourages continuous improvement through cycles of planning, action, observation, and reflection, which are essential when teaching complex subjects such as ecology and scientific inquiry. According to Elliott (1987), this approach allows educators to assess and refine their teaching strategies in real-time, leading to more effective and meaningful learning experiences for students.

The stages of this action research model are as follows: (a) identifying the issue or problem, (b) planning and implementing the intervention, (c) collecting data, (d) analyzing the data, and (e) reflecting and revising the teaching approach based on the findings. In the context of this research, the first step involved identifying specific ecological concepts or research skills that need improvement. Next, a teaching intervention was planned, by integrating more hands-on environmental projects or inquiry-based learning activities. The data collection phase involved gathering student feedback, observing classroom interactions, and assessing student understanding through the completion of the interventions. The data was analyzed to determine the effectiveness of the intervention, followed by a reflective process where the teacher evaluates the success of the approach and makes necessary adjustments for further cycles of action.

This cyclical process allows for continuous refinement of teaching practices, ensuring that students develop strong research skills and gain a deeper understanding of ecological issues. By using Elliott's action research model, the researcher engaged in an ongoing process of self-improvement, ultimately creating a more dynamic and effective learning environment.

Participants, Sampling and Intentional Selection

To select the participants for this research, convenience sampling was used. According to Golzar, Jawad & Noor (2022) convenience sampling is employed when subjects are selected based on their availability and accessibility to the researcher. This sampling method is useful because it allows for the efficient selection of participants who are readily available and can provide relevant data for the research. According to several authors (Creswell & Guetterman, 2019; Gay et al., 2012; Hernández et al., 2014), convenience sampling involves selecting a sample based on its availability and accessibility. In other words, participants are contacted and selected due to their availability (i.e., anyone who wishes to participate and meets the necessary criteria). However, the results can only be generalized to individuals with the same characteristics, not to the entire population.

Creswell and Guetterman (2019) and McMillan (2012) stated that in intentional selection, cases are chosen because they have or can provide the necessary information to answer the research questions, thereby helping to understand or learn about the phenomenon. Specifically, McMillan (2012) pointed out that with an almost typical intentional selection, participants are chosen who embody, exemplify, or represent specific characteristics of a group or similar subjects. This type of selection aims for the richness, depth, and quality of the information, rather than quantity.

The study was conducted in a bilingual private school located in the metropolitan area of San Juan, Puerto Rico. The target group consisted of middle school students from 6th and 7th grades who were enrolled in the Science course. These students were selected through convenience sampling and represented a diverse group in terms of gender and educational backgrounds, reflecting a transitional academic stage typical of intermediate-level learners. A total of 57 students participated in the study, including 36 females and 21 males. This demographic information helped to contextualize the sample and highlight its relevance to the study's objectives.

In accordance with ethical research standards, informed consent was obtained from the students' parents or legal guardians, and student assent was also requested. This protocol ensured compliance with ethical guidelines for the protection of human subjects in educational research.

Action Plan

The action plan aimed to address three main difficulties identified in the research process: the lack of research skills and abilities, the lack of confidence in conducting scientific analyses, and the difficulty in connecting learned knowledge to practical applications. The actions started with three pre-tests to assess students' baseline understanding and attitudes. These included two instruments developed by the UPR BioRets Program: Science Attitudes Questionnaire (IAC in Spanish), which consisted of 31 statements and a Nature of Science Literacy Questionnaire (PANC in Spanish), which included 35 statements. Also, an Aquatic Ecology and Research Competencies Assessment, developed by the researcher, containing 36 items. These assessments will serve as the foundation for understanding students' attitudes and knowledge before the intervention.

The *Aquatic Ecology and Research Competencies Assessment* was a standardized instrument developed by the researcher to evaluate students' scientific competencies, ecological knowledge, and data analysis skills within the context of aquatic ecology education. The assessment consisted of 36 multiple-choice items and was designed to be administered as both a pre-test and post-test to measure learning gains resulting from educational interventions. This instrument was organized into eight thematic sections: scientific research competencies, macroinvertebrate identification and classification, water quality testing, knowledge of the three shrimp species found in El Yunque, the use of macroinvertebrates as bioindicators, emerging aquatic stressors (such as over-the-counter analgesics), ecological awareness, and data analysis related to macroinvertebrate populations. Most questions featured four response options with only one correct answer, except for the final section, which included true/false statements based on experimental data interpretation.

From a statistical perspective, the instrument demonstrated strong content validity, as it aligned closely with core learning objectives in scientific inquiry and aquatic ecology. Its structure supported the use of reliability analysis (e.g., Cronbach's alpha) to assess internal consistency, and the pre/post format allowed for paired-sample t-tests or non-parametric equivalents to examine educational impact. Overall, the instrument served as an effective tool for evaluating the outcomes of hands-on scientific research experiences and contributed valuable data on students' growth in scientific understanding and ecological awareness.

To address the first challenge, the action plan involved practical, hands-on activities that encourage students to engage in essential research tasks such as observation, classification, measurement, data collection, and analysis. By incorporating field sampling activities, students experienced opportunities to observe and classify macroinvertebrates, measured water quality, and collected data, thus helping them develop research competencies in a structured, supportive environment. These tasks were carefully guided to ensure students build their skills progressively.

To tackle the second difficulty—lack of confidence—the action plan incorporated team-based activities. Students collaborated on experiments, allowing them to share knowledge, support one another, and troubleshoot together. This collaborative approach improved scientific tasks and fostered a sense of shared accomplishment. Regular feedback provided students with opportunities to evaluate their progress and build confidence in their ability to conduct scientific analyses.

The third challenge, connecting learned knowledge to practical applications, was addressed through real-world experiences. By studying macroinvertebrates and their role in freshwater ecosystems, students directly linked their classroom learning to environmental issues. This hands-on approach helped students understand scientific concepts more deeply but also foster ecological awareness by demonstrating the relevance of science to real-world problems. Activities such as macroinvertebrate field sampling, water quality testing, and studies of freshwater disruptors were implemented to allow students to engage with real-world ecological issues and connect acquired knowledge to ecological awareness. After the interventions, a post-test measured changes in students' research competencies and ecological awareness. These evaluations assessed improvements in students' confidence and their ability to perform scientific analyses.

Table 2. *Action Plan Structure*

	Context	Involved Subjects	Specific Action	Resources/Materials	Responsible Person	Worksheet	Analysis	Expected Results or Findings
Lack of research skills and competencies	Classroom	6th and 7th graders	Description and classification of the Tolerance Index in Macroinvertebrates	Field sampling kits, macroinvertebrate guides, water quality testing kits	Teacher	Identification and Classification - Macro Dot Detectives!	Descriptive statistics, observation notes	Improved research skills, ability to classify and describe macroinvertebrates, enhanced data collection skills
Lack of confidence in the ability to conduct scientific analysis	Classroom	6th and 7th graders	Collaborative group water quality testing and results presentation sessions	Experiment materials, group work guides	Teacher	Water Quality Testing I (Kit) and II (Sensors)	Data collection, analysis and communication	Increased student confidence, enhanced data collection, analysis and communication skills
Difficulty connecting learned concepts to practical applications	Classroom	6th and 7th graders	Field sampling of macroinvertebrates, ecological studies	Field sampling kits, water testing tools, ecological study guides	Teacher	Exploring Macroinvertebrates with Research Intro Worksheets • Research Intro I: Decapoda in the El Yunque Tropical Rain Forest • Research Intro II: Morphometric and Weight Analysis in Shrimps	Descriptive statistics, content analysis	Students will connect classroom concepts to real-world applications, increased ecological awareness
Limited understanding of the impact of studied topics on ecological awareness	Classroom	6th and 7th graders	Real-world ecological issue studies, focusing on macroinvertebrates	Study materials on freshwater ecosystems, case studies on environmental issues	Teacher		Descriptive statistics, case study evaluation	Enhanced ecological awareness and understanding of the environmental impact of macroinvertebrates

Weak ecological awareness due to lack of knowledge integration	Classroom	6th and 7th graders	Integration of macroinvertebrate study into broader environmental context	Resources on biodiversity, ecology texts, multimedia tools	Teacher	• Research Intro III: Macroinvertebrate Safari • Research Intro IV: Tracking the Effect of Emergent Stressors in Fresh Water	Statistical analysis, content analysis	Improved ecological awareness, integration of knowledge into practical environmental issues

Explanation of the Action

The pedagogical approach of this action was experiential, using laboratory practices and research techniques. The action started with three pre-tests to assess students' baseline understanding and attitudes. These included: a Science Attitudes Questionnaire, which consisted of 31 statements; a Nature of Science Literacy Questionnaire, which included 35 statements; and an Aquatic Ecology and Research Competencies Assessment, that contained 36 items. These assessments served as the foundation for understanding students' attitudes and knowledge before the intervention.

Following these pre-assessments, students engaged in Macroinvertebrates-Based Learning Interventions, which involved a variety of hands-on activities designed to improve their research competencies, practical skills, and ecological awareness. The effectiveness of these interventions was evaluated through data collected from students, using different worksheets to track their progress as completed or not completed. This allowed for a comprehensive understanding of the students' growth in research skills, confidence, and ecological awareness.

Intervention Activities and Detailed Explanations

Identification and Classification - Macro Dot Detectives!

- **Activity Explanation**: In this activity, students worked as "Macro Dot Detectives" to identify and classify various macroinvertebrates. The participants used a key chart to guide their observations and classification. The activity emphasized the development of observation and classification skills, as well as an understanding of macroinvertebrates' roles in freshwater ecosystems. Students were encouraged to closely examine macroinvertebrates under magnifying glasses, as well as microscopes, and used identification guides to distinguish different species.

- **Resources**: Macroinvertebrate identification key chart, magnifying glass, microscopes, petri dish, identification guide
- **Expected Outcome**: Students will develop the ability to identify and classify macroinvertebrates, increasing their understanding of species diversity and their roles in ecosystems.
  - **Outcome Achieved**: Students successfully identified and classified various macroinvertebrates during hands-on activities and demonstrated a clearer understanding of species diversity and ecological roles through worksheet responses and group discussions.

- **Water Quality Testing I (Kit) and II (Sensors)**
  - **Activity Explanation**: Students conducted water quality testing using both simple kits and advanced sensors. They measured parameters such as pH, dissolved oxygen, and other water quality indicators. This activity aimed to improve students' confidence in conducting scientific tests, fostering a deeper understanding of how water quality impacts aquatic life. By using hands-on testing methods, students connected theoretical knowledge to real-world applications in environmental science.
  - **Resources**: Water quality testing kits, pH meter, dissolved oxygen meter
  - **Expected Outcome**: Students will acquire the skills to test and analyze water quality, with a focus on understanding the implications for ecosystem health and learning to use scientific instruments.
    - **Outcome Achieved**: Students demonstrated the ability to test and analyze water samples using scientific instruments such as kits and sensors. They interpreted, discussed and shared the results accurately

about the ecological implications of water quality in relation to macroinvertebrate populations.

- **Exploring Macroinvertebrates with Research Intro Worksheets**
    - **Activity Explanation**: This activity involves several research introduction worksheets that help students explore macroinvertebrates from multiple angles. The worksheets will cover different research topics, including:
        - **Research Intro I**: Decapoda in the El Yunque Tropical Rain Forest
        - **Research Intro II**: Morphometric and Weight Analysis in Shrimps
        - **Research Intro III**: Macroinvertebrate Safari
        - **Research Intro IV (Perform as a science fair research project - Optional)**: Tracking the Effect of Emergent Stressors in Fresh Water

These activities allowed students to connect learned concepts with real-world ecological issues. They developed skills in observation, measurement, data analysis, and ecological interpretation, enhancing their understanding of freshwater ecosystems.

- **Resources**: Workshop about Shrimp species, measuring tools, Research worksheets, macroinvertebrate samples
- **Expected Outcome**: Students will improve their skills in data collection and analysis, while deepening their understanding of macroinvertebrate ecology and the impacts of environmental stressors on aquatic life.
    - **Outcome Achieved**: Students accurately collected and analyzed data related to macroinvertebrate populations in various water samples. They demonstrated a deeper understanding of ecological relationships

and discussed how environmental stressors, such as pollution or habitat changes, affect aquatic life.

These activities were carefully designed to integrate research skills with hands-on experiences, building students' confidence in scientific analysis and their ability to apply classroom knowledge to practical ecological situations. Through these interventions, students will gain a more robust understanding of research methods and ecological concepts, leading to increased scientific literacy and awareness.

Table 3. *Explanation of the Action*

Action Activity	Activity Explanation	Use of Resources	Intervention Time	Instruments, Techniques, or Guides	Data Collection Moment	Type of Information
Identification and Classification - Macro Dot Detectives!	Students will identify and classify macroinvertebrates using a key chart. This activity develops skills in observation, classification, and analysis of species within freshwater ecosystems.	Macroinvertebrate identification key chart, magnifying glass, Petri dish, identification guide	1 week	Visual observation, comparison	During the activity	Identification of macroinvertebrates, abundance, species classification
Water Quality Testing I (Kit) and II (Sensors)	Students will use water quality testing kits and sensors to measure key parameters like pH and dissolved oxygen. This activity aims to foster confidence and understanding of scientific analysis in real-world environmental contexts.	Water quality testing kits, pH meter, dissolved oxygen meter	1 week	Water testing kits, pH meter, dissolved oxygen meter	During the activity	Water quality parameters (pH, dissolved oxygen, etc.)
Exploring Macroinvertebrates with Research Intro Worksheets	Students will explore macroinvertebrate research through four distinct worksheets: Decapoda in El Yunque, Morphometric and Weight in Shrimps, Macroinvertebrate Safari, and Lolli Tracking the Effect of Emergent Stressors in Fresh Water. These activities provide connections between learned concepts and practical ecological applications.	Research Intro worksheets, macroinvertebrate samples	2 weeks	Observation, measurement, data analysis	During the activity and post-activity	Macroinvertebrate characteristics, ecological roles, data analysis skills

Data Collection

Mills and Gay (2018) stated that the information collected in action research allows "the development of reflective practice, brings positive changes to the school environment (and to educational practices in general), and improves student outcomes and the lives of those involved" (p. 508). In this study, data was gathered using a combination of quantitative instruments to assess changes in students' research competencies, ecological awareness, and attitudes toward science before and after the intervention.

The main component of data collection is Inquiry for Action. Inquiry for Action involves the use of pre-tests and post-tests to measure students' initial competencies and attitudes as a baseline and then assess any changes following the implementation of the action plan (Mertler, 2023). These provided objective data to determine the effectiveness of the learning interventions. Additionally, checkmark rubrics will be used to monitor each step of the process, with students also tracking their own progress.

For this research, quantitative data was collected using pre- and post-measurements, specifically through three key instruments: the Science Attitudes Questionnaire, the Nature of Science Literacy Questionnaire, and the Aquatic Ecology and Research Competencies Assessment. These instruments were administered to the students before and after the intervention to measure changes in their attitudes toward science, understanding of scientific concepts, and research competencies. The pre-measurement established a baseline of students' initial knowledge and attitudes regarding science, research, and ecological issues. After the implementation of the action plan, the same instruments were used as post-measurements to assess any changes resulting from the learning activities. By collecting and comparing data from the pre- and post-tests, the study provided a clear picture of the impact of the intervention on students' scientific understanding, research skills, and ecological awareness. These measures were vital in determining whether the learning strategies implemented in the action plan had been effective in improving students' scientific and ecological abilities throughout the research process.

Instruments

A questionnaire is an instrument used to answer questions in order to measure attitudes, perceptions, opinions, or satisfaction regarding a particular topic (Creswell & Guetterman, 2019). A test is an instrument used to measure achievement (e.g., specific content), aptitude (e.g., physical, verbal), or psychological aspects (e.g., interests, personality) related to a particular subject or issue (McMillan, 2014; Medina & Verdejo, 2019). This is done to demonstrate or verify someone's knowledge or abilities (Real Academia Española, 2023). Regarding achievement, Medina and Verdejo (2019) stated that it measures how questions related to specific content are answered, that is, how well a person masters certain academic content.

The initial instruments for collecting quantitative data are the *Science Attitudes Questionnaire*, and the *Nature of Science Literacy Questionnaire*, and the *Aquatic Ecology and Research Competencies Assessment*. These instruments were selected based on their ability to assess students' research skills, scientific literacy, and attitudes towards science in a clear, structured manner. According to Creswell and Guetterman (2019), questionnaires are effective tools for obtaining quantitative data on attitudes, knowledge, and competencies, and are commonly used in educational research to measure change over time. The *Science Attitudes Questionnaire* contains 31 items, assessing students' views on science and research. The *Nature of Science Literacy Questionnaire* includes 35 items to evaluate students’ understanding of the scientific process and scientific inquiry. The *Aquatic Ecology and Research Competencies* Assessment, have

36 items to evaluate students’ knowledge of aquatic ecosystems, data collection skills, and research competencies.

The instruments consisted of multiple-choice questions, Likert-scale items, and open-ended questions, designed to assess both quantitative knowledge (e.g., facts about aquatic ecology) and qualitative understanding (e.g., students’ perceptions of science and research). The quantitative data were gathered using the *Science Attitudes Questionnaire*, and the *Nature of Science Literacy Questionnaire*, and the *Aquatic Ecology and Research Competencies Assessment*. By using these instruments, the researcher measured changes in students' research skills, understanding of scientific concepts, and attitudes toward science in a clear and measurable way. These tools were directly aligned with the goals of the study and provided critical data on the effectiveness of the learning interventions.

In addition to the primary instruments (pre- and post-measurements), secondary instruments were used to collect data throughout the intervention. These included scores from worksheets completed by students during each Macroinvertebrates-Based Learning Intervention. The worksheets were designed to assess students' understanding and engagement with the material covered in each session. By analyzing the worksheet scores, the researcher gained insights into students' ability to apply their knowledge of macroinvertebrates, aquatic ecosystems, and scientific research methods.

These worksheets served as an ongoing measure of students' learning progress and helped identify areas where further support or clarification was needed. The secondary instruments complemented the primary data collected from the pre- and post-tests, offering a more holistic view of how students developed their scientific and ecological abilities throughout the intervention.

Data Analysis

To ensure objective measurement and interpretation of student learning and engagement, both descriptive and inferential statistical analyses were conducted. A total of 57 students participated in the study, providing a sufficient sample for meaningful quantitative analysis. Descriptive statistics were used to summarize and organize the data collected from various instruments, such as pre- and post-tests and worksheets, making it easier to perform subsequent specific analyses and determine whether statistical assumptions were met (McMillan, 2016; Pardo & San Martín, 2010).

Measures of central tendency were applied to observe how the data were distributed around the center of the distribution, while measures of variability were used to examine how the data were spread out in relation to the center. These included the minimum and maximum scores, the mean to identify central tendencies, and the standard deviation to assess the variability of scores. These descriptive measures provided an overview of data distribution and guided the selection of suitable inferential tests based on assumptions such as normality.

For the inferential analysis, several statistical procedures were used to evaluate the effectiveness of the intervention. The Kolmogorov-Smirnov test was applied to assess whether the distributions of pre- and post-test scores conformed to a normal distribution, informing the decision between using parametric or non-parametric tests. When the data met the assumptions of normality, a paired sample t-test was conducted to examine whether there was a statistically significant difference between students' pre- and post-test scores.

To complement these analyses, Cohen’s d was calculated to determine the effect size of the intervention, offering a standardized measure of the magnitude of change in student performance. Through this quantitative analysis, the study gained a clearer picture of how students' understanding and skills evolved over the course of the intervention. This provided insights into whether reflection and active engagement played a critical role in enhancing students' learning outcomes, particularly in terms of their scientific competencies and ecological awareness.

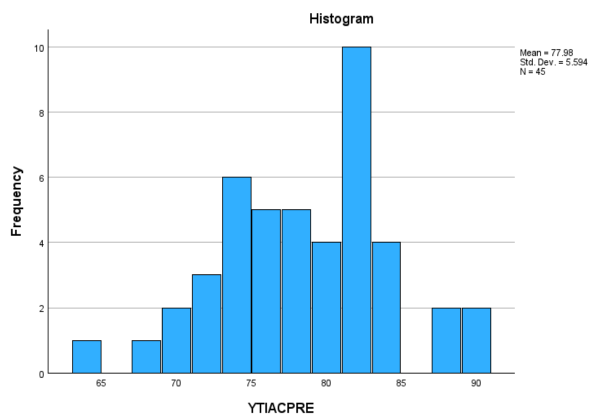
Results

Science Attitudes Inventory (IAC)

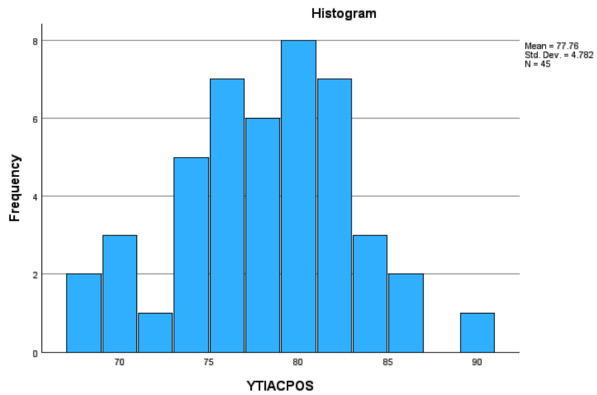
The Inventory of Attitudes Toward Science (IAC) was administered to 45 students to assess whether the intervention influenced students' attitudes and feelings about science. After data cleaning, only valid responses were included in the analysis. The lowest score slightly increased from 64 in the pre-test to 68 in the post-test, while the highest scores remained relatively stable (89 in the pre-test and 90 in the post-test). The mean scores showed almost no change, with an average of 77.98 (SD = 5.594) before the intervention and 77.76 (SD = 4.782) afterward.

Normality was confirmed for both sets of scores (pre-test: D = .105, p = .200; post-test: D = .090, p = .200). A strong positive correlation was found between the two sets of scores ($r = .549$, $p < .001$), suggesting consistency in student attitudes. However, the paired-samples t-test did not reveal a statistically significant difference between pre- and post-test scores, $t(44) = .300$, $p = .766$. The graph below presents a visual comparison of pre- and post-test scores on the IAC, demonstrating the stability of students' attitudes across the intervention period.

Graph 1. **Inventory of Attitudes Toward Science (IAC) – Pre Test Results**



Graph 2. **Inventory of Attitudes Toward Science (IAC) – Post Test Results**

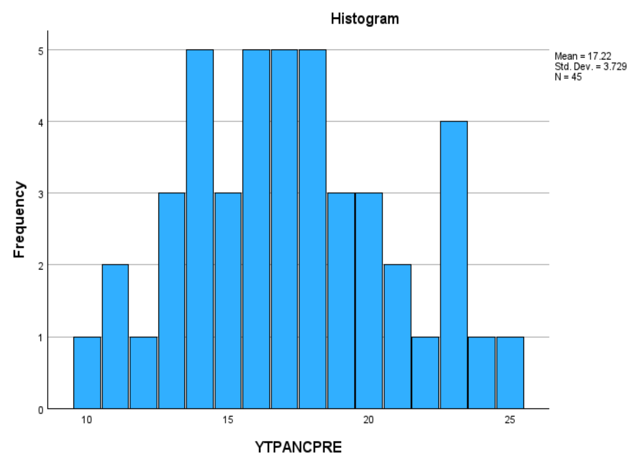


These results indicate that the intervention did not significantly affect students' attitudes toward science. It is possible that students already held positive attitudes, leaving little room for measurable improvement, or that the intervention primarily targeted cognitive gains rather than affective outcomes. Future iterations of the program might consider including components that more explicitly address and promote engagement and positive perceptions of science.

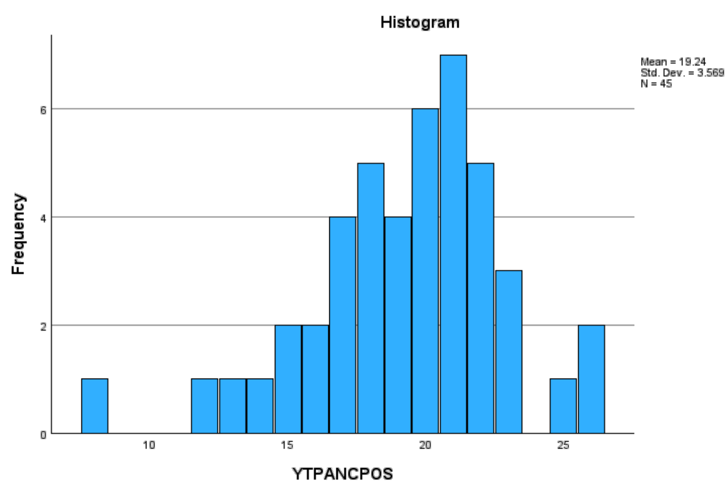
Nature of Science Literacy Test (PANC)

The Nature of Science Literacy Test (PANC) was used to assess students' understanding of the nature of science, with valid data collected from 45 students. Unlike the other assessments, the minimum score slightly decreased from 10 in the pre-test to 8 in the post-test, while the maximum increased from 25 to 26. Despite this variation, the mean score increased from 17.22 (SD = 3.729) to 19.24 (SD = 3.569), indicating overall improvement. The distribution of scores for both tests met the assumption of normality (pre-test: $D = .084$, $p = .200$; post-test: $D = .117$, $p = .140$). A weak, non-significant correlation was observed between the two sets of scores ($r = .173$, $p = .254$), suggesting limited consistency in individual performance between pre- and post-testing. Nevertheless, a paired-samples t-test revealed a statistically significant improvement in scores following the intervention, $t(44) = -2.891$, $p = .006$. The effect size, calculated with Cohen's d, was -0.431, indicating a moderate effect. The following graph displays the change in students' scores on the PANC, showcasing the moderate gains in science literacy resulting from the intervention:

Graph 3. **Nature of Science (PANC) –Pre Test Results**



Graph 4. **Nature of Science (PANC) – Post Test Results**



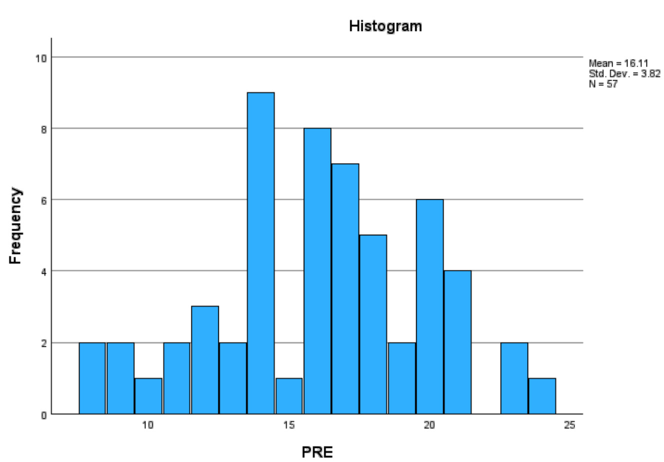
These results suggest that educational activities, particularly those emphasizing scientific inquiry and critical reflection, had a meaningful and measurable impact on students' understanding of the nature of science. The findings support previous research highlighting the value of active learning approaches in promoting scientific literacy.

Aquatic Ecology and Research Competencies Assessment

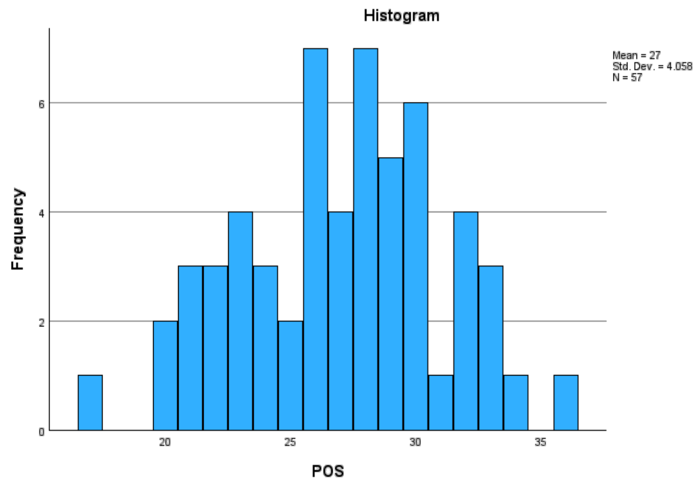
To evaluate the impact of the educational intervention on students' content knowledge, pre- and post-tests were administered to a group of 57 students. The lowest score on the pre-test was 8, increasing to 17 in the post-test. The highest score rose from 24 in the pre-test to 36 in the post-test. The average score also showed notable improvement, with the pre-test mean at 16.11 (SD = 3.820) and the post-test mean at 27.00 (SD = 4.058). A Kolmogorov-Smirnov test confirmed that the scores in both assessments followed a normal distribution (pre-test: D = .103, p = .200; post-test: D = .089, p = .200), satisfying the assumption necessary for parametric testing.

Given these results and the sample size (n > 30), a paired-samples t-test was conducted to compare the two sets of scores. A moderate and statistically significant positive correlation was found between pre- and post-test scores (r = .443, p < .001). The t-test result indicated a significant difference between the means, t(56) = -19.770, p < .001. Moreover, the effect size, as measured by Cohen's d, was -2.619, representing a very large effect. The following graph illustrates the shift in content knowledge scores from the pre-test to the post-test, highlighting the magnitude of the improvement:

***Graph* 5. Aquatic Ecology and Research Competencies Assessment – Pre Test Results**



***Graph* 6. Aquatic Ecology and Research Competencies Assessment – Post Test Results**



These findings demonstrate that the intervention led to a substantial and statistically significant increase in students' content knowledge, suggesting that the instructional strategies were highly effective.

The results from the three instruments demonstrated varied but meaningful outcomes following the intervention. Students showed significant gains in scientific knowledge and understanding of the nature of science, while their already high levels of attitude toward science remained stable. Together, these outcomes suggest a positive impact of the macroinvertebrate-based learning experience on both cognitive and affective dimensions of science education. These results must be viewed since a total of 57 students participated in and successfully completed the full cycle of interventions, which included the macroinvertebrate-based activities and all pre- and post-assessments. Attendance throughout the intervention was consistent, with minimal absences, and all students completed the required learning tasks and assessments within the planned timeframe. This full participation rate reflects strong student engagement and effective involvement in the intervention process, suggesting that the instructional strategies used were both accessible and motivating for the target group.

Discussion

The purpose of this study was to evaluate the effects of a macroinvertebrate-based learning intervention on sixth and seventh grade students' scientific research competence and ecological awareness. The intervention aimed not only to improve scientific knowledge but also to promote environmental understanding through active, skill-based learning. The results from three assessment instruments provided a comprehensive perspective on student outcomes and inform the interpretation of the research questions.

At the outset, the results of the pre-tests indicated that students possessed a foundational, yet limited, level of scientific research competence. This was particularly evident in the Aquatic Ecology and Research Competencies Assessment, where the average pre-test score was relatively low (M = 16.11 out of 36), pointing to gaps in students' grasp of basic scientific concepts and inquiry skills. Similarly, results from the PANC suggested a developing, though incomplete, understanding of the nature of science, with a pre-test average of 17.22 out of 30. These baseline scores demonstrate that prior to the intervention, students were in the early stages of acquiring both theoretical and procedural knowledge necessary for engaging in authentic scientific inquiry.

In contrast, the pre-test scores on the IAC were relatively high (M = 77.98 out of 100), suggesting that students already held favorable attitudes toward science and demonstrated a solid degree of ecological awareness. This finding is encouraging, as it reflects a pre-existing interest in and concern for environmental issues among the students. However, it also points to a potential maximum effect, which may help explain the lack of statistically significant gains in the post-test scores. In this context, the intervention may have served more as a reinforcement of existing positive attitudes rather than a promoter of measurable change. This interpretation aligns with findings by Neurohr et al. (2023), who noted that students with high initial interest in nature often display stable pro-environmental behaviors that are less likely to shift significantly through short-term educational interventions.

The post-intervention results demonstrated significant gains in both content knowledge and understanding of the nature of science. The mean score on the Aquatic Ecology and Research Competencies Assessment increased substantially to 27.00, a statistically significant improvement with a very large effect size (Cohen's d = -2.619). This suggests that students not only acquired more factual knowledge but likely improved in skills such as observation, classification, and evidence-based reasoning—core components of scientific research competence. Gains in the PANC scores, while more modest, were also statistically significant (M = 19.24 post-test; Cohen's d = -0.431), indicating improved understanding of how science operates, including its methods, limitations, and the role of collaboration and communication. These outcomes affirm the effectiveness of the intervention in promoting critical scientific thinking and research-based learning. These outcomes affirm the effectiveness of the intervention in promoting critical scientific thinking and research-based learning, consistent with findings by Bhaw, Kriek, and Lemmer (2023), who emphasized the importance of coherence in students' scientific reasoning for the development of meaningful science competencies.

While no significant change was observed in students' attitudes toward science, the consistently high scores across both pre- and post-tests reflect a stable and positive outlook toward environmental issues. This suggests that the intervention-maintained students' engagement and did not diminish their enthusiasm—an important consideration for long-term retention and the potential for sustained interest in science. It may also indicate that the affective goals of the program were met not by increasing attitudes quantitatively, but by keeping them meaningfully connected to real-world environmental contexts. Which aligns with findings by Solé-Llussà and Aguilar (2022), who noted that students often require targeted instructional strategies to develop foundational science process skills effectively.

The design of the intervention—centered on inquiry-based, hands-on exploration of local ecosystems through macroinvertebrate collection and analysis—appears to have played a critical role in these outcomes. By engaging students in authentic scientific practices such as data collection, classification, interpretation, and teamwork, the program succeeded in connecting scientific concepts to environmental awareness through experiential learning. This approach aligns with broader educational research, which emphasizes the importance of active learning and contextually grounded instruction in promoting deeper understanding and skill development. Similar conclusions were drawn by Sesen and Tarhan (2011), who found that inquiry-based laboratory activities significantly enhanced school students' conceptual understanding and attitudes toward Science, underscoring the value of structured, student-centered investigation across scientific domains.

Taken together, the findings suggest that macroinvertebrate-based learning can be a powerful tool for improving students' scientific competence, especially when the curriculum is intentionally designed to integrate both content knowledge and inquiry skills. Inquiry-based instruction has been shown to not only enhance conceptual understanding but also promote critical thinking and reflective learning, as evidenced by Dewi et al. (2021), who demonstrated its effectiveness in developing these skills among prospective teachers. At the same time, fostering ecological awareness is essential in cultivating responsible environmental behavior. As noted by Vilcapoma-Malpartida et al. (2023), promoting environmental consciousness among students requires educational experiences that go beyond content delivery and engage learners in real-world environmental contexts. To that end, future actions or interventions could incorporate elements such as reflective journaling, environmental action projects, or community engagement to deepen students' connection to ecological issues and nurture a sense of environmental identity and responsibility. This study demonstrated that structured, experiential interventions can significantly enhance scientific understanding while supporting positive attitudes toward science and the environment. The results offer promising insights for educators seeking to cultivate both cognitive and affective dimensions of scientific literacy in middle school students, particularly through localized and relevant environmental education strategies.

Limitations

While the findings of this study offered valuable insights into the impact of macroinvertebrate-based learning interventions on scientific competence and ecological awareness, several limitations should be considered when interpreting the results. First, the study relied on a design without a control group, which limits the ability to attribute observed changes solely to intervention. Second, sample size (N=57) may restrict the generalization of the findings. The sample consisted of students from a specific educational context, likely sharing common demographic, geographic, or curricular characteristics. Third, while the quantitative instruments provided valuable data on knowledge gains and attitudinal shifts, they may not have captured the full scope of student learning or environmental engagement. Qualitative measures such as student reflections, interviews, or observations were not included, which could have enriched the understanding of student experiences and the affective impact of the intervention.

Another limitation relates to the potential ceiling effect observed in the Inventory of Attitudes Toward Science. Because students began the study with already high scores in this area, the intervention may have had limited room to produce measurable improvements. This constrains the interpretation of null results in attitudinal change, as a lack of significant difference does not necessarily imply a lack of impact. Lastly, the study was conducted over a relatively short time frame, which may have limited the opportunity to observe long-term changes in students' attitudes or behaviors related to science and the environment. Sustained interventions and follow-up assessments could provide a more comprehensive picture of lasting impact. Despite these limitations, the study provided important evidence supporting the effectiveness of experiential, inquiry-based science education, and lays the groundwork for future research and program refinement.

Conclusion

This study explored the impact of a macroinvertebrate-based learning intervention on the scientific competence and ecological awareness of sixth and seventh grade students. The results revealed significant gains in both content knowledge and understanding of the nature of science, indicating that the intervention was effective in promoting scientific research competence. Although no significant changes were observed in students' attitudes toward science, their consistently high levels of ecological awareness suggest that the program successfully reinforced positive environmental values. The findings support the value of experiential, inquiry-driven learning that integrates environmental contexts into science education. By engaging students in authentic scientific practices—such as observation, classification, data analysis, and collaboration—the intervention provided meaningful opportunities for skill development and conceptual growth.

While limitations related to design, measurement, and scope must be acknowledged, the outcomes of this study offer promising implications for educators seeking to foster deeper scientific literacy and environmental consciousness in young learners. Future research and program development should continue to refine this approach, ensuring it is both pedagogically sound and personally relevant to students as they become informed, empowered participants in the scientific and ecological challenges of their world. First, incorporating a control or comparison group in future research designs would strengthen causal claims and allow for more robust evaluation.

Additionally, integrating qualitative methods—such as student interviews, reflective journals, or classroom observations—could provide richer insights into the personal and cognitive impacts of the intervention. Given the limitations of the current attitude scale, it would also be beneficial to refine or supplement attitudinal measures to capture more specific shifts in ecological awareness and environmental responsibility. Expanding the duration of the intervention may allow for more sustained learning and behavioral changes, and including components that promote action-oriented learning—such as community-based projects or student-led advocacy—could further deepen environmental engagement.

Finally, broadening the participant sample to include students from diverse regions and educational settings would enhance the generalizability of the findings. In summary, the macroinvertebrate-based intervention proved to be an effective strategy for promoting scientific literacy and inquiry skills among middle school students. By addressing the recommendations above, future implementations have the potential to not only strengthen cognitive outcomes but also foster a more profound and enduring sense of environmental stewardship in young learners.

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