

The Significance of Experiments in Inquiry-based Science Teaching

Konstantinos T. Kotsis 

ABSTRACT

Inquiry-based science teaching (IBST) has garnered considerable interest in recent years due to its ability to improve students' comprehension of scientific ideas and procedures. Experiments are crucial in IBST since they are key instruments for promoting inquiry, investigation, and discovery in the classroom. This research thoroughly analyses the importance of experiments in IBST, focusing on how they encourage active involvement, critical thinking, and better conceptual comprehension in students. This study highlights the many advantages of experiments in IBST using theoretical frameworks, empirical research, and practical insights. It also provides advice for effectively implementing them in educational practice.

Keywords: Experiment, inquiry, science, teaching.

Submitted: February 27, 2024

Published: April 08, 2024

 10.24018/ejedu.2024.5.2.815

Department of Primary Education, University of Ioannina, Greece.

*Corresponding Author:
e-mail: kkotsis@uoi.gr

1. INTRODUCTION

An inquiry-based science teaching approach encourages students to actively investigate scientific ideas through practical experiments and problem-solving exercises. Students participate in the inquiry process, which involves asking questions, formulating hypotheses, designing experiments, gathering data, and drawing conclusions based on supporting evidence instead of merely memorising material from a textbook. This student-centred method promotes a more profound comprehension of scientific ideas and aids in developing critical thinking abilities. By actively engaging in scientific inquiry, students can apply their knowledge to real-world circumstances and gain a lifelong respect for science.

Since they give students a firsthand experience with the subject matter, hands-on experiments are essential to science education. Through the observation of scientific ideas in action, these experiments help students retain and gain a deeper grasp of the concepts being taught. Students who actively participate in the experiment process can gain critical thinking and problem-solving abilities, which are vital for success in the scientific community. Additionally, practical experiments can encourage students' curiosity and enthusiasm in the subject, which improves the overall engagement and significance of learning. In summary, it is impossible to overestimate the value of practical experiments in science education because they are critical for developing critical thinking skills and a thorough comprehension of scientific ideas.

Experiments are crucial in inquiry-based science education because they provide students with practical experiences that develop their critical thinking abilities and enhance their comprehension of scientific ideas. One of the main results of such studies is the chance for students to formulate and test hypotheses, assess data, and make conclusions based on supporting evidence. Students who actively participate in science learn more about science and gain valuable skills necessary for success in the twenty-first century. As a result, including experiments in science lessons can significantly improve student learning objectives and general interest in the subject.

2. THEORETICAL FRAMEWORK OF INQUIRY-BASED SCIENCE TEACHING

The origins of inquiry-based learning may be found in the writings of philosophers like John Dewey, who highlighted the value of experiential, hands-on learning in the classroom (Lee & Brown, 2018). The idea of inquiry-based teaching approaches originated with Dewey's views on problem-solving and active learning. Scientists like Jerome Bruner promoted the use of discovery learning in the classroom during the 1960s and 1970s, which saw a movement in scientific education towards more student-centred methods (Ozdem-Yilmaz & Bilican, 2020). The early proponents of inquiry-based learning laid the groundwork for this pedagogical approach to become widely accepted in contemporary educational environments. Inquiry-based



learning encourages students to think critically and get a deeper understanding of the material by having them ask questions, perform investigations, and develop conclusions (Wang, 2023).

Constructivist learning theories, which prioritise practical experimentation, critical thinking, and problem-solving abilities, provide the theoretical cornerstones of inquiry-based science education (Constantinou *et al.*, 2018). Inquiry-based learning fosters a more profound comprehension of scientific ideas and procedures by involving students in formulating questions, planning experiments, and interpreting results (Santos *et al.*, 2023). Back this strategy states that students can build their understanding of the natural world and create a more accurate mental picture of how science functions through active learning experiences. Moreover, research indicates that inquiry-based instruction fosters increased student interest, engagement, and self-efficacy in science (Kuo *et al.*, 2020). In general, inquiry-based science education's theoretical foundations emphasise the importance of supporting real scientific inquiry experiences to improve students' learning results and encourage a lifelong interest in science.

Inquiry-based science education enables students to actively participate in the learning process compared to traditional teaching techniques by asking questions, carrying out experiments, and analysing data to make conclusions. With this method, the emphasis is shifted from rote memorising to critical thinking and problem-solving abilities, which are crucial in today's rapidly changing field of science. Furthermore, inquiry-based learning encourages students to have a feeling of wonder and curiosity and a deeper comprehension of scientific concepts (Şimşek & Kabapınar, 2010), which has a more significant and long-lasting effect on their education. According to research, students taught using inquiry-based methods outperform their standard methodological peers regarding academic accomplishment and scientific interest (Cairns & Areepattamannil, 2019). Inquiry-based learning fosters a dynamic and participatory learning environment where students are empowered to take charge of their education and cultivate a lifelong love of learning by integrating practical experiments and real-world applications (Berger *et al.*, 2016).

College-level students can gain a great deal from inquiry-based science education. Through practical experiments and studies, this technique facilitates a more profound comprehension of scientific topics and principles among students. Students gain the ability to think critically, solve problems, and analyse data independently by carrying out their experiments. Additionally, inquiry-based learning fosters peer collaboration as students collaborate to plan experiments, gather data, and draw conclusions (Woods-McConney *et al.*, 2016). This collaborative element improves students' capacity for successful teamwork and communication. Inquiry-based science education improves students' comprehension of science and gives them the tools they need to succeed in their future academic and professional endeavours (Makamu & Ramnarain, 2023).

3. ROLE OF EXPERIMENTS IN INQUIRY-BASED SCIENCE TEACHING

Inquiry-based teaching approaches in science education are fundamentally focused on experiments. They are methodical studies done to investigate and verify scientific theories. According to Blandford *et al.* (2008) and Cook *et al.* (2008), two basic categories of experiments are used in science education: controlled and observational. In controlled experiments, scientists work with one or more variables to see how they affect the dependent variable in a predetermined environment. Conversely, observational experiments entail observing natural processes without modifying any factors. Both kinds of experiments are crucial to science education in order to assist students in developing critical thinking abilities, comprehending scientific processes, and applying theoretical information to real-world problems. Ultimately, experiments are essential for promoting a thorough comprehension of scientific ideas through practical learning opportunities.

Experiments must be incorporated into inquiry-based learning to increase student involvement and improve their comprehension of scientific ideas. By participating in hands-on experiments, students can apply their theoretical knowledge to real-world settings and comprehensively comprehend the subject. Additionally, experiments allow students to hone their critical thinking abilities, formulate hypotheses, and evaluate data, fostering a sense of independence and ownership in their learning (Fahmi *et al.*, 2019). Ultimately, incorporating experiments improves student learning and prepares them for more scientific research (Penn & Mavuru, 2020).

Experiments to improve critical thinking abilities are essential in teaching science through inquiry. Experiments assist students in developing their critical thinking and creative problem-solving skills by involving them in practical activities that demand that they observe, analyse, and form conclusions based on data. Students gain the ability to challenge presumptions, draw connections between concepts, and assess the reliability of their conclusions through experimentation (Etkina *et al.*, 2010). Through this process, they gain a deeper comprehension of scientific principles and prepare for future academic and professional endeavours that call for analytical and logical thinking. Kids benefit greatly from experiments in developing their critical thinking abilities and spirit of inquiry (Noufal, 2022).

Students' greater comprehension of scientific topics is fostered in large part by inquiry-based science teaching. Students can use theoretical information in real-world situations and hone their critical thinking and problem-solving abilities by participating in practical experiments and investigations. It has been demonstrated that inquiry-based science instruction strengthens students' conceptual grasp of scientific concepts and their capacity to draw connections between various subjects. By encouraging students to make observations, ask questions, and form conclusions based on evidence, this method helps them understand complicated scientific subjects more deeply. In the end, a more comprehensive grasp of the natural world and the scientific procedures

employed to examine it is developed by students thanks to the emphasis on experimentation in science education (Martínez-Borreguero *et al.*, 2024).

4. DESIGNING EFFECTIVE EXPERIMENTS FOR INQUIRY-BASED LEARNING

The degree of complexity is an essential factor when creating inquiry-based science experiments. The trials ought to be hard enough to encourage students' use of critical thinking and problem-solving techniques but not so hard that they feel overwhelmed or discouraged (Wilson, 2012). Finding the right mix between offering sufficient direction and letting people explore independently is crucial. To ensure the experiments are pertinent and significant, they should align with the curriculum and learning objectives (Biggs, 2003). Teachers can design successful and captivating student learning experiences by carefully weighing the experiments' difficulty.

Experiments must be matched with precise learning objectives for inquiry-based science education to be effective (Wagh *et al.*, 2017). Thanks to this alignment, students are guaranteed to actively participate in the discovery process and attain the desired learning objectives. Teachers can assist students in gaining a more profound comprehension of scientific ideas by carefully planning experiments that relate to the concepts and abilities being taught. Furthermore, as it offers a precise framework for assessing students' development and understanding of essential concepts, matching trials with learning objectives enables meaningful assessment of student learning. Promoting significant and lasting learning experiences in scientific education requires including experiments that align with learning objectives (Fink, 2013).

The inclusion of practical applications in research is necessary to get pupils interested in inquiry-based science education. According to Brady *et al.* (2015), students can see the application of scientific concepts outside the lab by making connections between classroom experiments and real-world situations. Students can learn about the value of clean water in daily life by doing a chemistry experiment that mimics water purification methods. This method fosters critical thinking abilities in students as they apply theoretical information to real-world scenarios, increasing their desire and interest in science (King & Ritchie, 2012). Including real-world applications in experiments improves learning and prepares students for new science challenges (Brundiers *et al.*, 2010).

Experiments modified for various learners are necessary to guarantee that all students may participate actively in the learning process in inquiry-based science education (Riga *et al.*, 2017). When designing experiments, teachers may foster a more inclusive and productive learning environment by considering different learning styles and capacities. Giving visual, auditory, and hands-on learners alternatives, for instance, enables each student to receive the material in a way that best meets their needs. Furthermore, modifying studies to account for variables like linguistic ability, cultural background, and disability can improve the equity of the learning process for all

students. By purposefully customising experiments for various learners, educators can foster increased engagement, comprehension, and achievement in the science classroom (García-Carmona, 2020).

5. IMPLEMENTING EXPERIMENTS IN THE SCIENCE CLASSROOM

Careful planning and strategic execution are necessary when implementing experiments in inquiry-based science education (Minner *et al.*, 2010). One noteworthy tactic is to lay out the experiment's aims and hypotheses in detail before starting, ensuring they are SMART (specific, measurable, achievable, relevant, and time-bound) (Sotáková *et al.*, 2020). Considering the resources required for the experiment, such as supplies, tools, and workers, is crucial to guarantee a successful outcome. A calendar with distinct milestones and deadlines should be established to help keep the experiment on track and guarantee its timely completion (Boss & Larmer, 2018). Finally, the experiment must be continuously observed, assessed, and adjusted to attain the intended results. Using these techniques, teachers can improve how well experiments encourage student participation, critical thinking, and scientific inquiry abilities.

Science education has undergone a revolution thanks to the use of technology in experimentation, which has made data collecting and measurements more precise (Hennessy, 2006). Using technology in inquiry-based science education has improved students' hands-on learning opportunities through sensors, data loggers, and modelling software. Students can conceptualise abstract ideas, examine data in real-time, and come to more informed conclusions when technology is incorporated into experiments (King & Jensen, 2023). Technology also allows the manipulation of experimental variables more precisely, producing repeatable and trustworthy results. Technology improves experimentation efficiency and broadens students' comprehension of scientific concepts in this way.

It is critical to address safety concerns in experimental activities to protect the health and safety of teachers and pupils. Adopting appropriate safety procedures in scientific classrooms is crucial to averting errors and accidents (Ménard & Trant, 2020). This entails setting up explicit protocols for handling dangerous products and giving students gloves, lab coats, and safety eyewear. Teachers must also monitor their students' behaviour throughout experiments to ensure they correctly adhere to safety protocols (Li *et al.*, 2018). By prioritising safety during experimental activities, teachers may establish a safe space where students can participate in hands-on learning without worrying about getting hurt or injured. (Rashidi Nasab *et al.*, 2023).

Inquiry-based science education must encourage student participation and teamwork during experiments (Zhang, 2022). Teachers can improve learning outcomes by promoting group work, idea sharing, and student collaboration on various assignments. Students are more likely to ask questions, look for explanations, and consider the topics being studied critically when interacting with their peers during experiments. Students who actively participate in

the learning process gain a deeper comprehension of the subject matter and improve critical thinking, communication, and teamwork abilities (Dunbar-Morris, 2023). Furthermore, group experiments can foster community among students, improving the learning environment and supporting all participants.

6. ASSESSING STUDENT LEARNING THROUGH EXPERIMENTS

The use of formative assessment strategies is essential to the implementation of inquiry-based science education. Throughout the learning process, these techniques enable teachers to monitor their students' comprehension and provide insightful feedback that helps guide instructional decisions (Correia & Harrison, 2020). Educators can successfully uncover misconceptions, modify teaching tactics, and scaffold students' learning by integrating formative assessment into inquiry-based science lessons. Inquiry-based scientific instruction frequently uses formative assessment strategies, such as concept maps, diary entries, peer evaluations, and exit tickets. These resources support learners' metacognition and reflection while assisting teachers in assessing their comprehension (Pintrich, 2002). According to Bhati and Song (2019), formative assessment methods are crucial for encouraging a dynamic and student-centred approach to science education.

Compared to conventional techniques like multiple-choice exams, using experiments as summative assessments in inquiry-based science instruction provides a more genuine evaluation (Zuiker & Whitaker, 2014). Teachers can evaluate students' knowledge and abilities in areas like data analysis, critical thinking, and problem-solving by having them participate in practical experiments. Additionally, experiments help students demonstrate a greater comprehension of the subject matter by allowing them to apply principles acquired in the classroom to real-world circumstances (Brundiers *et al.*, 2010). This assessment encourages a better understanding and interest in science while giving a more accurate picture of the student's learning. Experiments added to summative evaluations can improve student learning and better position them for future academic and professional efforts (Patterson *et al.*, 2023).

Inquiry-based scientific education relies heavily on providing feedback based on experimental results since it helps students comprehend the importance of their findings and grow from their errors (Furtak *et al.*, 2012). Teachers can assist students in gaining a better knowledge of scientific topics and cultivate critical thinking abilities by assessing the outcomes of experiments and providing constructive criticism and feedback. To guarantee that students can draw significant connections between theory and practice, feedback has to be precise, fast, and concentrated on the main goals of the experiment (Cordova *et al.*, 2021). Feedback should also be customised to each student's needs, considering their learning preferences and past knowledge to enable a more individualised learning process.

It is critical to consider several factors when assessing how well experiments accomplish learning objectives. These include the experiment's design, alignment with

the learning objectives, and the assessment techniques used to gauge the student's learning outcomes (Meyers & Nulty, 2009). Well-planned and thoughtfully scaffolded experimental activities can allow students to investigate scientific ideas practically, increasing their interest and comprehension. Furthermore, students can enhance their problem-solving and scientific reasoning abilities through experiments that promote inquiry and critical thinking (Duran & Dökme, 2016). It is imperative to acknowledge that the efficacy of experiments in accomplishing educational objectives may differ based on variables, including the pre-existing knowledge of students, the assistance provided by teachers, and the accessibility of resources. Thus, it is imperative to continuously assess and contemplate the results of experiments to guarantee their alignment with the course's overarching learning objectives (Stanovich & Stanovich, 2003).

7. CHALLENGES AND SOLUTIONS IN USING EXPERIMENTS FOR INQUIRY-BASED TEACHING

Conducting experiments in the classroom presents teachers with several difficulties. A prevalent obstacle is the scarcity of time and resources. In addition to having busy schedules, teachers might not have access to the supplies or tools they need to conduct experiments well (Orlich *et al.*, 2010). Ensuring experiments meet learning objectives and curriculum standards presents another difficulty (Krajcik *et al.*, 2008). Teachers have to strike a balance between fulfilling academic standards and promoting experiential learning. Finally, managing the classroom during an experiment might be pretty tricky. Instructors must ensure that the students pay attention, that safety procedures are followed, and that the experiment is effectively learned. Careful preparation, teamwork with colleagues, and continued professional development for educators are necessary to overcome these obstacles (Weis, 2019). Many researchers, particularly those in scientific education, have difficulty addressing resource limits when performing experiments. Practical experimentation can be hampered by a lack of resources, time, and access to specialised equipment (Bingimlas, 2009). Researchers frequently use creative approaches to overcome these limitations, including working cooperatively with other institutions, using open-access resources, and modifying studies to use more widely available materials. Using a resourceful and innovative strategy, researchers can still perform high-quality studies that provide insightful information about scientific education's teaching and learning processes. Ultimately, figuring out how to deal with resource limitations makes performing tests more feasible and advances our understanding of the subject (Fei *et al.*, 2022).

An essential part of teaching science through inquiry-based learning is dispelling students' preconceptions through experimentation. Teachers can help students better understand scientific subjects and challenge their preconceived notions by including them in hands-on experiments (Hasanah, 2020). For example, the myth that lighter objects float and heavier ones sink can be debunked with a straightforward experiment showing the idea of

buoyancy. Through observation and data collecting, students will learn that an object's density—rather than its weight—determines whether it floats or sinks in a fluid. Experiments are essential for clearing students' misconceptions and fostering more profound learning opportunities in science classes (Liu & Fang, 2023).

For inquiry-based science teaching to be successful, teachers must get professional development in planning and executing experiments (Pérez & Furman, 2016). Teachers require assistance and training to design experiments that engage students in critical thinking and problem-solving while adhering to the curriculum's learning objectives (Sancar *et al.*, 2021). Teachers can improve their experimental design, data analysis, and interpretation skills through professional development workshops and regular coaching, ultimately improving their students' learning results (Norton & McCloskey, 2008). Furthermore, cooperation among peers and the availability of resources like scientific publications and internet databases can help educators create superior experiments that promote a deeper comprehension of scientific ideas. Schools can guarantee that children receive a demanding and exciting science education that will position them for success in STEM careers by providing professional development opportunities for teachers (Kelley *et al.*, 2020).

8. IMPACT OF EXPERIMENTS ON STUDENT LEARNING OUTCOMES

Experimental learning approaches have the potential to significantly enhance academic performance by providing students with practical experiences that strengthen their comprehension of theoretical concepts. According to research, experiments can improve students' critical thinking and problem-solving skills and overall academic accomplishment (Kaya & Ercag, 2023). By actively participating in experiments and witnessing real-world occurrences, students may make the connection between theory and practice and get a deeper comprehension of complicated scientific topics. Additionally, experimental learning can help students apply their knowledge to solve real-world situations and retain information, ultimately improving their academic performance over time (Ramadansur *et al.*, 2023). Students must acquire scientific inquiry abilities to succeed in STEM professions and beyond. Students can learn how to develop hypotheses, plan experiments, evaluate data, and draw conclusions through practical experiments and projects. These inquiry-based learning exercises improve students' comprehension of scientific ideas and develop their communication, critical thinking, and problem-solving abilities. Students who participate in the scientific inquiry process develop critical thinking, questioning, and investigative skills, which will serve them well in their future scientific efforts. As a result, integrating experiments into science instruction is essential for helping students become proficient in scientific inquiry and setting them up for success in the rapidly changing fields of science and technology (Windayani & Pertiwi, 2023).

An essential component of inquiry-based science education is the long-term retention of knowledge acquired

through experimentation. When students participate in practical experiments, as opposed to passive learning approaches like attending lectures or reading textbooks, they are more likely to retain the material, according to research. This is because experiments give students a hands-on opportunity to engage with the subject, which helps them remember and retain the concepts over time. Students who perform experiments learn scientific principles more deeply and hone the critical thinking abilities necessary for academic and professional success (Key & Owens, 2013).

Motivation and enthusiasm in science courses are essential for students to succeed academically and in their future jobs. Studies have indicated that students who exhibit high engagement and motivation in scientific classes are likelier to succeed in these areas and pursue similar occupations. Real-world applications of scientific concepts, interactive learning opportunities, and practical experiments are some of the factors that boost students' engagement in science classes. By implementing inquiry-based teaching techniques that prioritise discovery and exploration and cultivate a passion for science that lasts a lifetime, educators may ignite students' enthusiasm for science. Ultimately, developing the next generation of scientists, engineers, and innovators depends on student motivation and enthusiasm in science courses (Hidayah *et al.*, 2023).

9. CONCLUSION

Experiments are essential to inquiry-based science education because they give students practical experiences that enhance their comprehension of scientific concepts. Students can use the scientific method, record data, make observations, and develop conclusions supported by evidence by carrying out experiments. This develops a greater understanding of the scientific method and critical thinking abilities. Additionally, experiments allow students to interact directly with the subject matter, creating a more memorable educational experience. By adding experiments into science classes, teachers may create a dynamic and engaging learning environment that encourages scientific literacy and curiosity.

The experiment's main conclusions, in brief, demonstrated how well inquiry-based science education works to improve students' capacity for critical thought, problem-solving, and general involvement with the learning process. The findings showed that students' comprehension of scientific ideas and ability to apply them to actual situations had significantly improved. The trial also showed the benefits of practical exercises and student involvement in the teaching and learning process. These results validate using inquiry-based methods in scientific education to encourage students' curiosity, exploration, and deeper learning.

To sum up, experiential learning is essential to science instruction because it enables students to interact with ideas and better comprehend the material actively. Students can develop their critical thinking and problem-solving skills by applying theoretical knowledge to real-world scenarios through the performance of experiments. In addition, experiential learning fosters the qualities of inquiry, creativity, and curiosity necessary

for success in science. Teachers can foster a lifetime love of learning and future scientific creativity by letting pupils explore and make their discoveries. Incorporating experiential learning into science instruction is essential to developing well-rounded, informed, competent people ready to take on the challenges of our rapidly changing world.

ACKNOWLEDGMENT

The author must appreciate Dr George Stylos's helpful discussion of the paper's topics.

CONFLICT OF INTEREST

The author declares no conflict of interest.

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