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Review Article

The Impact of Inquiry-Based Learning in Science Education: A Systematic Review of Student Engagement and Achievement

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About Article

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ABSTRACT

This systematic review examines the impact of inquiry-based learning (IBL) on engagement and achievement for students in secondary science. This review uses 35 empirical studies that were selected from an initial sample of 497 records, combining biological, chemical, physical, and general science literature to examine how IBL impacts students' behavioral, cognitive and emotional engagement beyond academic achievement. The results also include technology-enhanced learning (TEL) practices, including mobile learning, virtual laboratories, and augmented reality, with a focus on technology integration with pedagogy and blended learning models. The synthesis suggests that IBL represents a deep learning construct (critical thinking, metacognitive skills, and scientific reasoning), which happened most effectively when students had some degree of structured autonomy and a teacher to facilitate learning. The use of technology as a means to increase student engagement was maximally effective when integrated as a support for cognition; rather than simply using technology for the sake of using it. A primary consideration from this review is that IBL depends on teachers being intentional with their planning overall; especially with planning inquiry-based lessons, establishing productive classroom environments, and providing necessary instructional supports and resources. The synthesis contributes to the educational knowledge base in science education and offers frameworks and findings that will help educators and policymakers in the ongoing process of designing equitable, sustainable, and meaningful inquiry practices in science education.

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1. INTRODUCTION

In recent years, Inquiry-Based Learning (IBL) has developed as a powerful approach in secondary science education, largely because it can foster the higher-order thinking skills that adolescents will need in addressing complicated and uncertain contexts that are sometimes labeled VUCA volatility, uncertainty, complexity, and ambiguity (Antonio & Prudente, 2024). In a world that is increasingly complex and changing, scientific literacy is no longer a matter of recall of facts but should include abilities to analyze, evaluate, and create skills that will use scientific reasoning and problem solving (Alarcon *et al.*, 2023; Savelsbergh *et al.*, 2016). IBL aims to accomplish this by engaging students in structured investigation practices that resemble real science (Bennett *et al.*, 2018; Lazonder & Harmsen, 2016).

IBL presents both opportunities and challenges in secondary school settings. At this stage, students are developmentally ready to ask questions, form hypotheses, and think abstractly, making them especially receptive to inquiry-based learning. However, they still need structured guidance, motivational support, and well-organized classrooms to strike the right balance between independence and direction. Hence teachers need to separately manage the potential for independent inquiry against the need for curricular considerations and behavioral controls. When implemented effectively, IBL allows adolescents at the secondary level to create scientific understanding through experimentation, interpretation of data, and reflection that develops critical thinking and problem-solving skills (Nunaki *et al.*, 2019; Yuliati *et al.*, 2018).

While inquiry-based learning approaches can be implemented across educational levels, the importance of IBL for secondary education is especially relevant. In secondary school, students start to shift from localized or concrete types of learning experiences to more abstract and interdisciplinary reasoning across biology, chemistry, and physics (Firman *et al.*, 2019; Balta & Sarac, 2016). Nonetheless, research shows that, while IBL can support connectedness and engagement, it is ultimately contingent on factors such as teacher knowledge, classroom management, and access to digital technologies or laboratories (Struyf *et al.*, 2019; Chi *et al.*, 2018).

Building upon this context, the present systematic review focuses exclusively on secondary science education to examine how different inquiry-based methods influence both student engagement and academic achievement. It also investigates how technology integration, instructional design, and teacher readiness interact to shape IBL outcomes. By bringing together findings from recent studies, this review seeks to show how IBL can be adapted to meet the needs of adolescent learners emphasizing the teaching supports and school conditions that make inquiry a lasting and meaningful part of secondary science learning.

2. LITERATURE REVIEW

2.1. Theoretical Frameworks Supporting Inquiry-Based Learning

2.1.1. Constructivism and Student-Centered Learning Theories

According to the educational theorist Fogarty, IBL is based on constructivist pedagogical paradigms which highlight

knowledge construction as an active, contextualized process rather than passively being absorbed. The constructivist view, as articulated originally by Piaget, Vygotsky and Bruner, asserts that learning occurs when the learner engages in active exploration, social interaction and personal reflection with prior knowledge. In this case, inquiry-based instruction changes the locus of learning from the teacher to learner, which change guides students more actively and collaboratively engage with scientific content (Lazonder & Harmsen, 2016). This movement is in keeping with pedagogical approaches that put the individual more at the center, giving both autonomy and collaboration, alongside support on a need-to-know basis so as to manage learning most appropriately (Savelsbergh *et al.*, 2016). Reviews of education research show a positive impact of constructivist-inspired IBL on students' scientific reasoning, evidentiary thinking and self-regulation (Bernard *et al.*, 2019). In addition, there is a shift in secondary science teachers' orientation towards constructivist and inquiry-based frameworks that are more heavily focused on the modeling of scientific concepts through real world applications (Alarcon *et al.*, 2023). The move away from teacher-centered learning toward an inquiry-based student-centered paradigm is a signature change in the pedagogy of science and supports creativity in the development of the curriculum and assessment.

2.2. Cognitive Engagement and Metacognition in Inquiry-Based Practices

Inquiry-based learning environments support much more than building content knowledge in students; inquiry-based learning methods get students to think more specifically about how they learn. As students engage in and work through problem-solving tasks, they become increasingly conscious of their own thinking processes and managing those thinking processes (Lazonder & Harmsen, 2016; Savelsbergh *et al.*, 2016). When learners are given the chance to design experiments, test their ideas, and make sense of the data they collect, they practice important metacognitive skills such as planning ahead, checking their own understanding, and reflecting on the results (Nunaki *et al.*, 2019; Yuliati *et al.*, 2018). These capacities are essential for deeper engagement in thinking and problem solving, which have been linked to improved scientific literacy; students who progress beyond mere fact retention to conceptual understanding of natural phenomena also demonstrate stronger problem-solving abilities and adaptive thinking (Antonio & Prudente, 2024; Bernard *et al.*, 2019). Nevertheless, empirical evidence also suggests that the extent of metacognitive benefits gained from IBL may be influenced by individual factors such as gender and prior knowledge (Nunaki *et al.*, 2019; Ural, 2016). At one end are studies that suggest well-designed inquiry tasks to be equitably effective as they report minimal gender differences between male and female students in metacognitive development post-intervention (Nunaki *et al.*, 2019). Other work corroborates the sense that IBL improves problem-solving, especially when complemented with experimental simulations and structured scaffolding (Yuliati *et al.*, 2018). Furthermore, laboratory-based inquiry activities designed to create a sense of student control have demonstrated efficacy in regards to improving the engagement of students in scientific inquiry and critical



thinking skills (Struyf *et al.*, 2019).

2.3. Motivation and Engagement Theories Related to IBL

According to this theory, when learners' basic needs for competence, autonomy, and relatedness are satisfied, they are more likely to promote intrinsic motivation and maintain engagement in their activities (Deci & Ryan, 2000). Traditional pedagogical approaches, often based around a lecture, are likely to not meet the motivation needs of students, whereas inquiry-based contexts afford students with a degree of control, choice, collaboration, and opportunities for deeper engagement (Wood, 2019; Struyf *et al.*, 2019). Research also supports that instruction that is autonomy-supportive, that is, respects students' autonomy, can increase engagement and motivations to learn science (Fan *et al.*, 2021). For example, studies framing the findings in terms of SDT has demonstrated, for instance, that stronger perceptions of teacher-student relationships lead to more reported willingness to engage in, or follow-up with, inquiry-based learning (Wood, 2019). Studies using learning analytics report that a relationship exist between supportive teacher behaviors and behavioral engagement with blended courses and online science coursework, emphasizing the importance of the instructor's presence and feedback (Fan *et al.*, 2021). Additionally, qualitative studies in STEM classrooms demonstrated that warm socio-cognitive climates and student-centered pedagogies support both cognitive and affective engagement of an academic nature (Struyf *et al.*, 2019).

2.4. Inquiry-Based Learning Modalities in Science Education

2.4.1. Traditional Inquiry-Based Learning Models

Enforcing the traditional IBL approach, proper guidance and hands-on experimentation help students enhance their conceptual understanding and improve their skills (Ural, 2016; Lazonder & Harmsen, 2016). Teachers provide structured support to enable learners to gradually take ownership of structuring investigations and determining relevant evidence (Savelsbergh *et al.*, 2016; Sukariasih *et al.*, 2019). Through iterative questioning, hypothesis generation, and results analysis, students' scientific reasoning and inquiry abilities strengthen over time (Nunaki *et al.*, 2019; Firman *et al.*, 2019). Action research within classroom contexts demonstrates that the application of guided inquiry learning models, often assisted by tangible science kits or laboratory resources, can significantly enhance knowledge acquisition and inquiry skills, as quantified through pre- and post-test assessments and observation protocols (Fan *et al.*, 2021). Research utilizing classroom-based action research designs describe significant gains in conceptual understanding and inquiry skills following repeated cycles of guided inquiry (Sukariasih *et al.*, 2019). Moreover, a number of studies examining physics education interventions based on real, authentic inquiry reveal positive effects on conceptual understanding and self-efficacy, compared with traditional physics instruction, that draw on participative student-led explorations (Fernandez, 2017).

2.4.2. Inquiry-Based Learning with Technology Integration

Inquiry based science education and the use of new technologies propels the development of new ways to promote

performance and to establish imaginative, creative solutions to support learning experiences of students (Bidarra & Rusman, 2016). Utilizing mobile devices in inquiry-based learning which is called Mobile inquiry-based learning (mIBL), changes the nature of traditional inquiry. Mobile inquiry-based learning (mIBL) places inquiry into activity in which learners are able to attempt various experiments, collect data and compare their findings to a real (or contextual) environment (Liu *et al.*, 2020). Mobile learning is akin to mIBL in taking inquiry out of the classroom but retaining structure (Liu *et al.*, 2020; Alarcon *et al.*, 2023). Systematic reviews of mIBL in secondary science indicates that implementation approaches vary, as do outcomes and limitations, such as available technology and the teacher's readiness (Liu *et al.*, 2020). Additionally, VR/AR has received strong attention as an immersive platform that simulates scientific phenomena and environments, allowing for more experiential learning and motivation for students (Zhang & Wang, 2021; Yilmaz, 2018). Yet, critiques of the research suggest that to date most the designs of VR/AR are focused on providing the enabling technology, not a holistic pedagogy or cognitive process, such as critical thinking (Zhang & Wang, 2021). In support of this view are a number of other studies (Hamed & Aljanazrah, 2020), which suggest that virtual experiments in physics labs can, under certain conditions and by being carefully designed to involve active learning strategies and inquiry skills throughout the lab experience, have good effects on learner achievement and practical skills.

2.4.3. Project-Based and Problem-Based Learning as Inquiry Forms

Project-Based Learning (PrBL) and Problem-Based Learning (PBL) are structured inquiry approaches that put learning in complex, real-world problems and authentic knowledge-building processes. They have the same important principles that inquiry-based learning (IBL) establishes, such as student-driven inquiry, collaboration, and iterative problem-solving (Merritt *et al.*, 2017; Lazonder & Harmsen, 2016). Studies of PBL implementation in K-12 STEM education highlight important features including problem-centered learning, active collaboration, and integration with scientific practices like inquiry and reflection (Markula & Aksela, 2022). Even though it has potential, research provides evidence showing that PBL implementation sometimes falters, particularly in terms of higher-order questioning and interdisciplinary collaboration (Hall & Miro, 2016). Within reviews of early-grade mathematics and science classrooms, PBL shows promise, but the lack of faithful implementation and consistent definitions has been shown to limit effects of PBL on academic achievement (Merritt *et al.*, 2017). Ultimately, teachers receiving considerable professional development and adequate building support is important for PBL (project-based learning) to be successful and for students to be engaged in active learning (Thibaut *et al.*, 2018; Alarcon *et al.*, 2023).

2.5. Effects of Inquiry-Based Learning on Student Achievement

2.5.1. Meta-Analytic Evidence of IBL's Impact on Academic Outcomes

Cumulative evidence from multiple meta-analyses confirms



the effectiveness of inquiry-based learning (IBL) in enhancing student achievement in the sciences (Antonio & Prudente, 2024; Savelsbergh *et al.*, 2016). One extensive meta-analysis that examined students from diverse backgrounds and research designs reported an overall weighted effect size of Hedges' $g = 0.893$, indicating a strong and positive impact of inquiry-based teaching on higher-order thinking and learning in science (Antonio & Prudente, 2024). A related meta-synthesis on guided inquiry approaches, such as Process Oriented Guided Inquiry Learning (POGIL), found moderate but significant gains in performance outcomes, along with a substantially greater likelihood of passing science courses compared to lecture-based instruction (Lazonder & Harmsen, 2016). Likewise, research on cultivating inquiry skills found moderate effect sizes in a range of educational contexts, adding support to the idea that IBL can enhance cognitive and scientific reasoning (Firman *et al.*, 2019). Further consistent with these results, Arifin *et al.* (2025) reported significant positive effects of inquiry-based learning on secondary school students' critical thinking skills in science, which were particularly strong gains for classes that included hands-on experiments along with active involvement of students. Collectively, this body of research challenges persistent doubts about the effectiveness and feasibility of inquiry-based teaching in formal science education (Alarcon *et al.*, 2023; Bernard *et al.*, 2019).

2.5.2. Subject-Specific and Educational Level Variations

Students' achievement has shown improvement through IBL, although to different degrees within and across grade levels and subject areas. Meta-analyses reveal that IBL is effective at various grade levels: primary, secondary, and tertiary levels. It is assuming that students in the elementary grades receive the highest gains because of the developmental nature of younger learners' improved learning with the guidance of structure (Antonio & Prudente, 2024; Savelsbergh *et al.*, 2016). Further, scientific disciplines respond differently to inquiry methods based on the content, as biology, physics, and chemistry all produce different challenges and resources based on the complexity of content and history of teaching (Balta & Sarac, 2016; Alarcon *et al.*, 2023). Authentic inquiry-based methods in physics, for example, illustrate that students' conceptual understanding has substantially improved (Fernandez, 2017). The efficacy of IBL strategies for students is contingent on other factors such as students' prior knowledge, the design of instruction, and inquiry models that are aligned with students' developmental levels and the demands of the subject (Lazonder & Harmsen, 2016).

2.5.3. Role of Teacher Support, Classroom Climate, and Instructional Moderators

Support from teachers, as well as the discipline structure afforded for the students in the classroom, will play a major role in whether or not inquiry-based learning will be a success, primarily for students with lower socioeconomic status. Analyses of PISA 2015 data reveal that classroom management and a disciplined learning atmosphere facilitate inquiry activities and science achievement while direct emotional support from teachers has a much smaller direct impact on gains in students' science achievement (Chi *et al.*, 2018). In open inquiry situations,

teachers' confidence in their subject knowledge and skill is essential, and systematic reviews emphasize the importance of ongoing professional development to help deepen the teachers' own knowledge and skill in inquiry pedagogy (Alarcon *et al.*, 2023). Laboratory-based studies further demonstrate that guided inquiry activities greatly support students' science achievement and attitudes when implemented by a prepared teacher and when the teacher provides formative assessment (Ural, 2016). Collectively, all the findings indicate that to implement IBL effectively requires strong support systems in place including teacher training along with a classroom climate that is welcoming to exploration so that students have a meaningful and equitable science learning experience.

2.6. Inquiry-Based Learning and Student Engagement

2.6.1. IBL's Influence on Behavioral, Cognitive, and Emotional Engagement

Inquiry-based learning inspires students to engage in real scientific practices, promoting their internal curiosity and interest. Observational and mixed-design studies reveal this form of learning inspires students to invest more time and energy on tasks, participate more intensely in inquiry activities and environments, and develop their own self-regulation strategies (Struyf *et al.*, 2019; Wood, 2019). Larger scale correlational studies are finding inquiry-based practices are related to increased behavioral engagement and cognitive engagement, citing supportive autonomy and STEM-focused guidance as strategies to help maintain students' interest and persistence in science learning (Fan *et al.*, 2021). Design attention to inquiry learning environments also elicits positive emotions, demonstrates reduced science anxiety, and motivates students, which combined support students' perceptions about science becoming relevant and approachable (Wood, 2019). Collectively, these dimensions of engagement create the foundation for broadening the classroom inquiry practices effecting improved academic performance and ultimately long-term scientific literacy.

2.6.2. Integration of STEM and IBL to Foster Engagement

The increasing blending of inquiry-based learning into wider STEM education promotes an impactful synergy to engage students. Research shows that when academic content is applied in real-world contexts and societal issues within integrated STEM programs, it was able to motivate students (Thibaut *et al.*, 2018). While inquiry has increasingly been included in interdisciplinary curricula, challenges for implementation still exist, particularly when scientific inquiry is coupled with engineering and technology components (Struyf *et al.*, 2019). These findings also support prior research that the importance of carefully designed instruction, along with effective teacher professional development that utilizes content integration as well as inquiry pedagogy are less likely to engage students in such complex learning situations (Hall & Miro, 2016).

2.6.3. Technological and Pedagogical Supports for Engagement in IBL

The merging of technology-based advances like mobile learning apps, serious games, and blended learning models,



possess multiple levels of support for shifting students' interest and engagement on inquiry-based activities. Mobile technologies, specifically, provide anytime anywhere access to inquiry-supporting resources, outside of traditional classroom settings, enhancing the educational experience and igniting interest unlike traditional practices (Liu, Zowghi, Kearney, & Bano, 2020). Augmented and virtual reality environments, although still evolving in pedagogy, have emerged as viable options for motivation, through the promotion of engaging and authentic environmentally-based learning (Zhang & Wang, 2021). Hybrid teaching models, including flipped classrooms or OpenCourseWare for inquiry activities, have even enhanced student enjoyment and opportunities for collaboration and engagement (Sun & Wu, 2016). This intersection of education--technology emphasizes the ongoing importance of inquiry engagement, in the recent era in education.

2.7. Gender, Socioeconomic Status, and Equity in Inquiry-Based Science Education

2.7.1. Gender Differences in Inquiry-Based Learning Outcomes

Research looking at gender in inquiry-based learning (IBL) has found that these approaches are powerful for developing metacognitive and inquiry skills for boys and girls. When experiments used pretest-post-test designs, studies found no significant differences in learning gains based on gender and that equitable teaching methods can help close typical achievement gaps (Nunaki *et al.*, 2019). In addition, when IBL is combined with culturally responsive practices, and classroom conditions and relationships are respectful and valuing, then this can increase student participation and lessen gender differences in engagement and grade performance (Brown, 2017). Future studies are needed to improve our understanding of the various factors of gender, and to facilitate learning tasks that are relevant for every student (Alarcon *et al.*, 2023).

2.7.2. Socioeconomic Status (SES) as a Moderator of IBL Effectiveness

Socioeconomic status continues to be a major factor affecting the achievement of inquiry-based science teaching. A significant body of teacher and student data analyses establish that the positive effects of inquiry on student learning depend on the degree of structure present in the classroom, while reducing the disadvantages students from lower socioeconomic class face (Chi *et al.*, 2018). Additionally, a meta-analysis supports that these types of interactive and structured inquiry are most effective in bridging the gap in achievement when taking place in a supportive learning environment (Savelsbergh *et al.*, 2016). Cross-national studies emphasize that equitable access to well-informed and well-designed inquiry instruction is a critical ingredient for non-privileged socioeconomic status students to be optimally acculturated into educational discourse (Oliver *et al.*, 2021). Therefore, purposeful pedagogical measures and policies have to be implemented to provide fair access to science learning through inquiry.

2.7.3. Culturally Responsive Inquiry and Inclusive

Science Teaching Practices

The integration of inquiry-based science teaching and culturally responsive pedagogy represents a formula for more equitable science learning. Educators designing inquiry activities that build on students' real life experiences and community backgrounds can leverage two pathways for success: embracing Indigenous knowledge systems, acknowledging the sociopolitical aspects of scientific topics, encouraging critical reflection (Brown, 2017). Building from research syntheses, culturally responsive inquiry practices uphold the different ways of knowing and enable deep conceptual understanding which is particularly important for engaging underrepresented student groups (Bennett *et al.*, 2018). In addition, the scientific attitudes and motivation among students with learning disabilities and diverse learning needs have been shown through the integration of culturally responsive content with inquiry-based teaching (Apanasionok *et al.*, 2019) giving emphasis to the inclusive potential of this approach.

2.8. Teacher Roles, Training, and Challenges in Implementing Inquiry-Based Learning

2.8.1. Teacher Knowledge, Attitudes, and Professional Development

In order for teachers to implement inquiry-based learning in an effective manner, they must have ample training, a positive attitude toward science teaching, and a great desire for professional development. Investigations assert the need for continuous training programs that develop teachers' content knowledge and pedagogical skills that support open inquiry (Alarcon *et al.*, 2023). Professional development experiments focusing on attitudes found a related increase in teacher self-efficacy, and a decrease in teacher anxiety related to science teaching, which was correlated with teaching higher quality science instruction. (Van Aalderen-Smeets & Van Der Molen, 2015). Also found in classroom studies were that teachers confident in their competence and comfort with inquiry settings were more likely to implement student-centered practices, and to foster engaged inquiry (Ural, 2016).

2.8.2. Classroom Management and Instructional Strategies Supporting IBL

Maintaining productive learning spaces remains a significant struggle in classrooms defined by amplified student self-direction and teamwork. Research has shown that classroom discipline and management strategies significantly impact how well student-directed investigation impacts achievement levels (Chi *et al.*, 2018). The combination of real tasks with formative assessment and real engagement has been demonstrated to help educators track progress and give feedback without compromising student inquiry engagement (Fernandez, 2017). Finding just the right measure of support and freedom is a key consideration for teachers. Lack of support and too much freedom can lead students to a state of cognitive overload and too much structure could limit the developmental advantages of the inquiry process (Sukariasih *et al.*, 2019). Thus, in order to achieve the educational benefits inquiry can provide teachers will have to strategically use scaffolding in conjunction with carefully developing the classroom structure.



2.8.3. Barriers and Enablers for Technology-Enhanced and Argument-Driven Inquiry

While the use of sophisticated technologies (VR/AR) and even mobile apps to inquiry-based learning is full of potentials, there are practical difficulties that are associated with this. While we have to admit that these tools grab the attention of students, research shows that many educators are not using them effectively in a way that is relevant to learning content (Zhang & Wang, 2021). Finally, approaches such as Argument-driven Inquiry (ADI) and its revised (rADI) emphasize structured instructional scaffolds for sense-making that promote open scientific discourse within the classroom (Weiss *et al.*, 2021). While the efficacy of such models in improving students' abilities to reason scientifically is well-established, variability in their implementation and differential degrees of teacher preparedness have historically curtailed their dissemination (Songsil *et al.*, 2019). To accomplish it requires more coordinated professional development and general higher-level support for working technology effectively into the classroom.

2.9. Comparative and Cross-National Perspectives on Inquiry-Based Instruction

2.9.1. International and Cross-Cultural Differences in Inquiry Implementation

The success of inquiry learning is contingent upon cultural standards, curriculum designs, and educational practices throughout the world. PISA 2015 data provided an interesting paradox: inquiry activities were often reported to occur, but were not universally correlated with scientific literacy levels (Oliver *et al.*, 2021). Most research states that inquiry thrives best when there are sound teacher support and an established sense of order in the classroom setting, underscoring the importance of context (Chi *et al.*, 2018). These studies suggest that inquiry-based learning should be deliberately contextualized to the culture and education context to be effective, in consideration of the curriculum and realities of teaching practice (Savelsbergh *et al.*, 2016).

2.9.2. Large-Scale Meta-Analyses on Inquiry and Adaptive Teaching Practices

Comprehensive meta-analyses on both adaptive and student-centered teaching practices show strong support for inquiry-based learning that increases academic effectiveness and emotional engagement to similar extents, but tends to show moderate effect sizes (Bernard *et al.*, 2019). The reviews emphasize that inquiry will take the most effect when teachers appropriately moderate their participation, pace their lessons, and let go of some control during a lesson. Additionally, inquiry-based methodologies seem to provide consistently higher and stronger benefits in STEM versus comparable areas of non-STEM content (Lazonder & Harmsen, 2016). Finally, these investigations suggest the importance of moderately structured support, suggesting that cognitive outcomes are improved through inquiry when appropriate structure is provided, mediating and alleviating potential disadvantages or undesirable factors associated with unguided discovery, and supporting the appropriateness of guided discovery (Savelsbergh *et al.*, 2016).

2.9.3. Policy Implications and Educational Reform for Promoting Inquiry

The successful implementation of inquiry-based learning (IBL) in classrooms will depend on the relationship to education policies and curricular experiences available to schools and teachers. For example, both the Next Generation Science Standards (NGSS) and more current STEM reforms have, as part of a national movement, introduced inquiry as a critical pedagogical means for classroom instruction. Nevertheless, schools still face consistent challenges brought on by inconsistent teacher preparation and a lack of classroom resources (Thibaut *et al.*, 2018). Research also indicates that marker-based augmented reality (AR) and mobile platforms are popular, and when implemented effectively, these platforms often result in increased student motivation and increased student achievement (Yilmaz, 2018). Virtual laboratories that utilize simulated and remote experiments are also an avenue for students to develop their understanding of disciplinary content and inquiry skills (Hamed & Aljanazrah, 2020).

2.10. Innovations and Emerging Trends in Inquiry-Based Science Education

2.10.1. Immersive and Argument-Based Inquiry Learning Environments

The immersive argument-based inquiry (ABI) model is a new way to combine the practices of scientific argumentation with a fully inquiry-based classroom experience. Reviewers note that ABI systems also generally prescribe designated roles for students and the teacher, guiding students to develop their understanding through dialogue, reasoning, and evidence-based argumentation (Weiss *et al.*, 2021). In these settings, students are encouraged to engage more deeply, sharpening their ability to argue scientifically and take part in meaningful science discussions (Songsil *et al.*, 2019). Models like ABI show strong potential for connecting traditional content learning with the modern skills students' need in science education (Rodríguez, Pérez, Núñez, *et al.*, 2019).

2.10.2. Integration of Inquiry with Virtual and Augmented Reality Technologies

Bringing VR and AR technologies into science inquiry is quickly becoming a powerful way to make learning more experiential. Studies show that their use in K–12 science classrooms is growing rapidly, with immersive simulations giving students new ways to explore concepts. The real difficulty isn't in bringing these tools into the classroom it's in making sure they're tied to teaching practices that push students to ask questions and think critically (Zhang & Wang, 2021). Studies also show that marker-based AR and mobile platforms are the most frequently used, and when handled well, they often spark higher motivation and better achievement (Yilmaz, 2018). Virtual labs, using simulations and remote experiments, also help students strengthen both their understanding of scientific concepts and their inquiry abilities (Hamed & Aljanazrah, 2020).

2.10.3. Hybrid and Blended Learning Models Supporting Inquiry

For example, hybrid and blended or flipped learning formats



mixed with instructor-led library research are being used as new approaches for creating engagement and serving learner diversity. The participatory blended learning in informal and formal contexts is geared by interactive support (ICT tools), which illustrates advanced models of frameworks like the Science Learning Activities Model (SLAM) (Bidarra & Rusman, 2016). Empirical studies suggest that flipped classrooms utilizing OpenCourseWare resources enhances student learning outcomes and improves student–teacher relationships. In addition, blended inquiry mediated by technology enhances student satisfaction rate and maximizes opportunities for cooperative learning (Sun & Wu, 2016). Further, blending learning is sought to integrate with project-based inquiry tasks to make better fulfillment of learning experiences and outcomes (Hall & Miro, 2016).

3. METHODOLOGY

3.1. Search Strategy

Extensive searches were undertaken in Scopus, Web of Science, ERIC, SpringerLink, ScienceDirect, and Wiley Online Library. Other searches were performed on Google Scholar and ProQuest Dissertations & Theses. Searches were for 2010 to 2024 publications and used Boolean operators with the following keywords:

- “inquiry-based learning” OR “guided inquiry” OR “open inquiry”
- AND “science education” OR “STEM education”
- AND “student engagement” OR “academic achievement”

Reference lists of the articles found were also hand-checked for additional included studies.

3.2. Eligibility Criteria

Inclusion criteria:

- Research specifically examining inquiry-based learning within the science education domain.
- The studies focused on findings related to either student engagement – either behavioral, cognitive, and/or emotional – and/or student learning outcomes including knowledge gains, reasoning skills, or academic grades.
- Research approaches included empirical research designs such as experimental, quasi-experimental, mixed methods, classroom action research or meta-analytic studies.
- Published in English.

Exclusion criteria:

- Exclusively conceptual/theoretical articles with no empirical evidence.
- Research that does not report measurable engagement or achievement measures.
- Non-English publications.

3.3. Screening Process

The inclusion process of studies followed the PRISMA 2020 guidelines meant for systematic reviews. There were 497 records identified through the initial search. Upon the removal of duplicates, 421 distinct studies were present. The titles and abstracts were screened to eventually exclude 312 studies. The full text was screened for eligibility for the remaining 109 articles, leaving with 74 studies excluded due to not meeting inclusion criteria. The synthesis comprised a final total of 35 empirical studies. PRISMA flow diagrams are widely used to depict this process, but in the current review, the information is given in tabular format (Table 1) to give a clear overview of each stage of identification, screening, eligibility, and inclusion.

Table 1. PRISMA Flow of Information Through the Review

Stage of Screening	Number of Records	Description
Records identified through database searching	497	Initial retrieval from databases & supplementary sources
Records after duplicates removed	421	Duplicates removed using reference management software
Records screened (titles & abstracts)	421	Assessed for relevance
Records excluded	312	Did not meet those inclusion criteria
Full-text papers screened for eligibility	109	Retrieved and examined in depth
Full-text articles omitted	74	Did not have empirical IBL focus, did not report achievement/enrollment, or lacked adequate data
Studies that were part of qualitative synthesis	35	End studies synthesized in review

3.4. Data Extraction and Synthesis

Data from each of the 35 included studies were systematically extracted using a structured matrix summarizing the research design, participants, inquiry-based learning approach, subject area, and reported outcomes on student engagement and academic achievement. A narrative synthesis was applied to integrate findings across studies with different research designs and outcome measures.

The synthesis followed three iterative phases. First, the

evidence from each study was summarized and described in detail. Second, relationships and patterns across engagement and achievement outcomes were identified and compared. Finally, the strength and consistency of these findings were evaluated. A thematic analysis was then applied to code and group recurring themes related to instructional strategies, technology integration, and contextual factors such as teacher readiness and classroom management. These coded themes were compared and refined through constant comparison,



resulting in two central domains academic achievement and student engagement presented in Table 2. This combined narrative thematic approach ensured analytical rigor by allowing both quantitative and qualitative evidence to inform the interpretation of results.

4. RESULTS AND DISCUSSION

The results across the 35 studies reviewed were summarized into two main themes of academic achievement and student engagement. Table 2 indicates the findings, along with an explanation and interpretation.

4.1. Academic Achievement.

Inquiry-based learning (IBL) steadily enhanced the performance of learners, yet differed in size by subject fields. In biology, there were considerable positive effects on concept knowledge and inquiry competency that were frequently validated by large effect sizes in meta-analyses and class interventions (Antonio & Prudente, 2024; Lazonder & Harmsen, 2016; Nunaki *et al.*, 2019; Sukariasih *et al.*, 2019). Parallel significant gains were also described in physics for problem-solving and reasoning, with action research and virtual laboratory interventions both finding improved comprehension (Fernandez, 2017; Hamed & Aljanazrah, 2020). For effects in chemistry, were moderate, such that it

was shown that guided-inquiry laboratory experiments for students were effective in reducing anxiety, but improving performance overall (Ural, 2016). In general, and integrated science, technology-enhanced inquiry approaches such as mobile learning and virtual labs consistently supported achievement across STEM contexts (Liu *et al.*, 2020; Zhang & Wang, 2021; Hamed & Aljanazrah, 2020).

4.2. Student Engagement.

Throughout the studies, IBL also facilitated multidimensional engagement. Behavioral engagement was a mediated variable, evident from students more actively participating, persisting, and collaborating, with action research and observational studies supporting this (Struyf *et al.*, 2019; Sukariasih *et al.*, 2019). Among engagement dimensions, cognitive engagement provided the most evidence. Some quasi-experimental and mixed-method studies have shown that inquiry learning supports an improvement in the areas of metacognition, critical thinking, and self-regulation (Nunaki *et al.*, 2019; Yuliati *et al.*, 2018; Struyf *et al.*, 2019). While the impact on emotional engagement was smaller but similar to other areas and slightly less significant, the impact is still important because inquiry-style approaches have been shown to reduce anxiety and increase motivation, particularly when teaching reflects student autonomy (Struyf *et al.*, 2019; Wood, 2019).

Table 2. Summary of Findings on Academic Achievement and Student Engagement.

Dimension	Findings	Supporting Evidence
Academic Achievement		
Biology	Strong positive impact on conceptual understanding and inquiry skills	Antonio & Prudente (2024); Lazonder & Harmsen (2016); Nunaki <i>et al.</i> (2019); Sukariasih <i>et al.</i> (2019)
Physics	Strong positive impact on reasoning and problem-solving	Fernandez (2017); Hamed & Aljanazrah (2020)
Chemistry	Moderate positive impact; reduced anxiety in labs	Ural (2016)
General/Integrated Science	Consistently positive across STEM contexts	Liu <i>et al.</i> (2020); Zhang & Wang (2021); Hamed & Aljanazrah (2020)
Student Engagement		
Behavioral	Moderate evidence; increased participation and cooperation	Struyf <i>et al.</i> (2019); Sukariasih <i>et al.</i> (2019)
Cognitive	Strongest evidence; development of metacognition and critical thinking	Nunaki <i>et al.</i> (2019); Yuliati <i>et al.</i> (2018); Struyf <i>et al.</i> (2019)
Emotional	Modest evidence; less anxiety and more motivation	Wood (2019); Struyf <i>et al.</i> (2019)

In conclusion, there is indication that inquiry-based learning is strong and sound pedagogy to support the learning of science and the participation of students in learning science at secondary school. Even though the effect size is diverse depending on content, instruction design, and classroom conditions, the findings are evident that IBL has the ability to enhance the level of conceptual understanding, develop critical thinking skills, and encourage students to learn science. Most importantly, the data also suggests identified areas of need must be further developed, such as strategically integrating

technology more responsive to students’ interests, teacher professional development in enabling students’ inquiry, and strategies to support engagement and learn for all students. These recommendations dovetail perfectly with the gaps identified at the start of this research, affirming the necessity of deliberate and adequately supported enactment of inquiry-based approaches in a bid to leverage their greatest benefits.

5. CONCLUSION

Research that has employed meta-analysis and systematic

reviews has found that inquiry-based learning (IBL) has a large positive effect on student academic achievement and student engagement in relation to science education. Inquiry approaches can also foster a higher-order cognitive and metacognitive skills for scientific literacy across varying contexts. Well-designed student-centered inquiry environments which foster behavioral, cognitive, and emotional engagement through facilitative roles of teachers and supportive classroom conditions are important (Antonio & Prudente, 2024; Bernard *et al.*, 2019). Finally, when appropriately integrated, advances in technology can be employed to sustain motivation and increase opportunity access for inquiry (Sukariasih *et al.*, 2019). The equitable instructional practice addressing gender, socioeconomic status, and cultural responsiveness is the key dimension for achieving the educational benefits of inquiry.

While some data is encouraging, various areas are less well explored. While technologies that are emerging within inquiry pedagogy have shown increased cognitive and affective results, minimal investigation of the subtleties that these improvements demonstrate exists. This leads to a lack of longitudinal studies across cultures and education systems, and poor knowledge regarding the longer-term effects this could have on IBL implementation as well as its ability to be adapted into heterogeneous settings (Brown, 2017). It is suggested that future research should take into account considering the intersections between gender, SES, and cultural identity concurrently in order to further our understanding of how each may affect participation and achievement in inquiry (Nunaki *et al.*, 2019; Van Aalderen-Smeets & Van Der Molen, 2015). Looking forward to a theory, practice, and policy framework better suited for various learners, these gaps must be addressed. Educators and policymakers can begin to bridge research and practice by thinking about how to prioritize inquiry-based teaching as well as professional learning established to work toward teacher content knowledge, pedagogical practices, and technology proficiency (Alarcon *et al.*, 2023). Classroom management is also important to continue to facilitate inquiry engagement, which recognizes good disciplinary climates in the classrooms (Weiss *et al.*, 2021). Culturally responsive teaching is required here, and policy in schools should inform curricular design utilizing technology that makes inquiry opportunities inclusive and efficient, supported by suitable laboratory resources (Sun & Wu, 2016). Stakeholders are urged to use these results in the design of scaling-up interventions for equitable, high-quality, and rigorous science learning for all.

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