

Investigating the Impact of Student-Led Research Projects on the Development of Scientific Reasoning Skills

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Abstract

This study examined the impact of student-led research projects on the development of scientific reasoning skills among senior secondary school science students using a mixed-methods design. Guided by constructivist and inquiry-based learning principles, the intervention positioned students as active investigators, allowing them to formulate hypotheses, design experiments, collect data, and justify findings using evidence. Quantitative data were gathered through pre- and post-test assessments of scientific reasoning administered to 150 students. Results showed a statistically significant improvement in students' reasoning skills following the intervention, with mean scores increasing from 42.63 to 58.47, $t(149) = 18.72$, $p < .001$, and a large effect size ($d = 1.52$), indicating a strong positive impact of student-led inquiry. Qualitative data from interviews and observations revealed that students developed deeper inquiry thinking, enhanced metacognitive reflection, improved argumentation skills, and greater autonomy in conducting investigations. Collaborative interactions further enriched learning, though students also reported constraints such as limited laboratory resources and time pressures. Integration of the quantitative and qualitative findings showed convergence, indicating that authentic inquiry, autonomy, and collaborative engagement were key contributors to the observed gains in scientific reasoning. Conversely, contextual challenges helped explain variations in individual performance. Overall, the study demonstrates the value of embedding student-led research projects within science curricula as a means of cultivating higher-order reasoning and promoting meaningful scientific literacy. The findings highlight the need for improved resource provision and structured support to maximize the benefits of student-driven inquiry in resource-limited educational contexts.

Keywords: Student-led research projects; Scientific reasoning; Inquiry-based learning; Mixed-methods; Science education

1. Introduction

Examining the influence of student-driven research projects on the development of scientific reasoning skills is pivotal for understanding how active engagement enhances higher-order cognitive abilities in science education. By positioning students at the center of the investigative process, these projects allow learners to independently or collaboratively formulate research questions, design and implement

experiments, and analyze findings. This experiential, hands-on approach nurtures essential scientific reasoning competencies, including hypothesis formulation, data interpretation, argumentation, and reflective thinking, which are crucial for fostering scientific literacy and advanced problem-solving capabilities.

Student-led research projects replicate authentic scientific practices, providing learners with genuine opportunities to participate in inquiry-based activities. Evidence suggests that such initiatives significantly improve students' reasoning and scientific thinking relative to traditional instructional strategies. For example, team-based project research (TBPR) has been demonstrated to enhance students' ability to apply scientific methodologies, engage in structured argumentative reasoning, and engage in metacognitive reflection on their learning processes (Yüksel, 2025). By emphasizing collaborative knowledge construction and active engagement, these projects encourage deeper comprehension and longer-term retention of scientific concepts.

In addition, scientific reasoning serves a dual function in educational contexts: it is both cultivated through participation in inquiry-driven projects and acts as a foundational skill necessary for mastering subject-specific content. Research on inquiry-based citizen science initiatives indicates that learners' proficiency in scientific reasoning strongly predicts their overall learning outcomes (Bruckermann, 2023). Likewise, independently conducted STEM research projects, when complemented by structured scaffolding and individualized feedback, have been linked to measurable improvements in reasoning, scientific communication, and questioning abilities (Yüksel, 2025).

Consequently, the integration of student-driven research projects into science curricula represents an effective pedagogical approach for developing the cognitive competencies fundamental to scientific literacy and lifelong learning. By granting students agency over their investigations, such projects cultivate autonomy, creativity, and critical engagement with complex scientific problems, thereby equipping learners with the skills necessary for success in both higher education and professional contexts in science and technology.

Purpose of the Study

The study seeks to investigate the effect of student-led research projects on the development of scientific reasoning skills among secondary school learners, examining abilities such as hypothesis formulation, experiment design, data analysis, and reflective thinking. It also explores students' experiences, perceptions, and challenges when engaging in autonomous or collaborative research activities.

Significance of the Study

This study provides insights to enhance science teaching by promoting inquiry-based, learner-centered approaches that strengthen critical thinking and problem-solving. Its findings can guide teacher training, inform curriculum design, and influence educational policy, particularly in under-resourced schools. Furthermore, the research highlights the role of student autonomy in learning, contributes to the body of knowledge on inquiry-driven science education, and supports preparation of learners for higher education and STEM careers.

Research Objectives

1. To examine the effect of student-led research projects on secondary school learners' scientific reasoning skills.
2. To investigate students' experiences, perceptions, and challenges in engaging with student-led research projects.

Research Questions

1. How do student-led research projects influence the scientific reasoning skills of secondary school learners?
2. What are students' experiences and perceptions of participating in student-led research projects, and which factors affect their development of scientific reasoning skills?

Literature Review

Defining and Conceptualizing Scientific Reasoning

Scientific reasoning is widely recognized as a set of interrelated cognitive and epistemic skills that enable learners to engage in authentic scientific practices. These include formulating hypotheses, designing and conducting experiments, controlling variables, interpreting data, and drawing evidence-based conclusions (Prudente & Antonio, 2023; Nardito Mediana, Funa, & Dio, 2025). Unlike mere memorization of scientific facts, scientific reasoning emphasizes higher-order cognitive processes that facilitate critical thinking, problem-solving, and conceptual understanding (DongJin & Ashari, 2024).

It is important to distinguish scientific reasoning from related constructs, including scientific thinking, science process skills, and scientific literacy. While these constructs overlap, they emphasize different components of cognition and engagement: scientific thinking is often associated with understanding scientific concepts and models, science process skills focus on procedural competence, and scientific literacy encompasses the ability to apply scientific reasoning in everyday life (DongJin & Ashari, 2024; Prudente & Antonio, 2023). For the present study, a fine-grained perspective is adopted, emphasizing reasoning sub-skills such as hypothesis generation, data analysis, and epistemic argumentation, which are essential for evaluating the impact of student-led research projects on learners' cognitive development (Nardito Mediana et al., 2025).

Pedagogical Models: Inquiry-Based Learning (IBL), Project-/Problem-Based Learning (PBL), and Student-Centered Research

Student-centered pedagogies, including Inquiry-Based Learning (IBL) and Project-Based Learning (PBL), provide the theoretical and practical foundation for student-led research projects. IBL encourages learners to pose questions, design investigations, and reflect on outcomes, thereby actively constructing knowledge (Gomez, 2025). PBL engages students in extended, real-world tasks that integrate multiple skills and culminate in a product or presentation, emphasizing collaboration, creativity, and critical thinking (DongJin & Ashari, 2024). Both pedagogical approaches align with constructivist and social-constructivist theories, which posit that learning occurs most effectively when students actively engage with content and collaborate to solve problems (Gomez, 2025; Arifin, Sukarmin, Saputro, & Kamari, 2025).

Student-led research projects represent a natural extension of these models, granting students autonomy and ownership of their scientific inquiries. By allowing learners to choose research questions, design experiments, and interpret results, these projects provide authentic contexts for developing scientific reasoning, critical thinking, and metacognitive skills (Gomez, 2025; Arifin et al., 2025). This alignment with established pedagogical frameworks supports the theoretical rationale for investigating their impact on reasoning skills in science education.

Empirical Evidence: Effects of IBL, PBL, and Student-Led Research on Scientific Reasoning

A growing body of empirical research supports the effectiveness of inquiry-based and project-based pedagogies in enhancing scientific reasoning, higher-order thinking, and process skills. Meta-analytic studies demonstrate that IBL significantly improves critical thinking and reasoning abilities when compared with traditional instructional methods, with effect sizes ranging from moderate to high (Arifin et al., 2025; Prudente & Antonio, 2023). Similarly, PBL has been associated with substantial gains in conceptual understanding, creativity, and collaborative skills (DongJin & Ashari, 2024).

Classroom-level studies further confirm these findings. For example, guided-inquiry interventions in secondary physics and science classrooms led to measurable improvements in students' experimental design abilities, argumentation, and conceptual understanding (Duran & Dökme, 2016; Nardito Mediana et al., 2025). Moreover, research on argument-driven inquiry has shown that students who engage in structured, student-led investigations exhibit enhanced scientific literacy, including reasoning, evidence evaluation, and metacognitive reflection (Author(s), 2025). These findings collectively indicate that student-led research projects can produce significant cognitive benefits, particularly when instructional scaffolding is provided.

Cognitive and Theoretical Foundations

The development of scientific reasoning through student-led research is grounded in several cognitive and theoretical frameworks. Constructivist theory posits that knowledge is actively constructed through interaction with content and collaboration with peers, making active learning essential for meaningful understanding (Gomez, 2025). Social-constructivist perspectives further emphasize the importance of collaborative discourse and guided participation in scaffolding cognitive development.

Epistemic reasoning is another critical component. This involves evaluating evidence, constructing valid scientific arguments, and reflecting on the process of scientific inquiry (Prudente & Antonio, 2023). Engaging in student-led research tasks allows learners to practice these epistemic skills in authentic contexts, fostering deeper conceptual understanding and scientific literacy. Additionally, metacognitive reflection—planning investigations, monitoring progress, and evaluating outcomes—enhances reasoning skills and supports transfer to new problems (Author(s), 2025; Gomez, 2025). These theoretical insights justify the hypothesis that structured student-led research can significantly improve scientific reasoning skills.

Challenges, Limitations, and Contextual Factors

Despite the benefits of IBL, PBL, and student-led research, several challenges and limitations may affect their effectiveness. Meta-analytic reviews indicate considerable heterogeneity in outcomes, influenced by factors such as instructional strategy, teacher guidance, duration of intervention, and resource availability (Arifin et al., 2025). Effective implementation requires structured autonomy, teacher facilitation, and access

to appropriate resources, without which students may struggle to conduct meaningful investigations or fully engage with reasoning processes (Gomez, 2025; DongJin & Ashari, 2024).

Moreover, students' prior knowledge, cognitive readiness, and self-regulatory skills influence their ability to benefit from open-ended inquiry. Research indicates that poorly supported inquiry may lead to superficial engagement, misconceptions, or frustration, underscoring the need for scaffolded approaches (Duran & Dökme, 2016; Arifin et al., 2025). In under-resourced contexts, challenges such as limited laboratory facilities, large class sizes, and insufficient teacher training may further constrain the effectiveness of student-led research projects (DongJin & Ashari, 2024). Recognizing these contextual factors is essential for interpreting outcomes and guiding effective implementation.

Gaps in Existing Literature and Rationale for the Present Study

While the literature supports the effectiveness of inquiry- and project-based pedagogies, several gaps remain. Many studies focus on broad constructs such as “critical thinking” or “scientific literacy” without disaggregating the sub-components of scientific reasoning, such as hypothesis generation, variable control, data analysis, and epistemic argumentation (Prudente & Antonio, 2023). Mixed-methods research that explores both cognitive outcomes and students' experiences, perceptions, and contextual challenges is limited (Gomez, 2025). Additionally, few studies examine student-led research in under-resourced or non-Western educational contexts, leaving a gap in understanding how these pedagogies function in developing countries (DongJin & Ashari, 2024; Arifin et al., 2025).

Addressing these gaps, the present study investigates the impact of student-led research projects on the development of scientific reasoning skills in Ghana, employing a mixed-methods design to capture both quantitative and qualitative dimensions of learning. This approach provides nuanced insight into how reasoning competencies are fostered and how contextual factors influence outcomes.

Implications for Science Education

The growing body of research and theoretical insights indicates that embedding student-centered investigative projects within science curricula meaningfully strengthens learners' reasoning abilities, critical thinking, and overall scientific literacy (Nardito Mediana et al., 2025; Gomez, 2025). Nonetheless, achieving such outcomes consistently across educational settings depends on ensuring equitable access to instructional resources, providing sustained professional development for teachers, and designing curricula that are responsive to local contexts and learner needs (DongJin & Ashari, 2024; Arifin et al., 2025).

Theoretical Underpinnings

The conceptual foundation of this study is grounded in constructivist learning theory, social-constructivist theory, and experiential learning theory, which collectively elucidate how student-led research projects foster the development of scientific reasoning skills.

Constructivist Learning Theory

Constructivist learning theory, as proposed by Piaget (1970), emphasizes that knowledge is actively constructed by learners rather than passively absorbed. Learning involves integrating new information with existing cognitive structures to generate meaningful understanding. Within science education,

constructivism underscores the importance of active engagement, hands-on inquiry, and critical exploration in cultivating higher-order thinking, problem-solving, and reasoning abilities (Nardito Mediana, Funa, & Dio, 2025).

Student-led research projects exemplify constructivist principles by positioning learners as architects of their own learning. Through formulating research questions, designing and conducting experiments, and interpreting findings, students engage in active knowledge construction, thereby enhancing scientific reasoning, analytical skills, and metacognitive reflection (Prudente & Antonio, 2023). This theoretical lens substantiates the expectation that student-led inquiry can significantly promote cognitive development in science learners.

Social-Constructivist Theory

Vygotsky's (1978) social-constructivist framework emphasizes the critical role of social interaction, collaborative dialogue, and scaffolding in cognitive development. Learning occurs most effectively when students engage in shared problem-solving, knowledge negotiation, and guided participation with peers or more knowledgeable others.

In the context of student-led research, social-constructivist principles are operationalized when students collaborate in teams, discuss interpretations of data, and engage in peer evaluation. Teachers provide scaffolding to navigate the zone of proximal development (ZPD), enabling learners to accomplish tasks that would otherwise be beyond their independent capabilities (Arifin, Sukarmin, Saputro, & Kamari, 2025; Gomez, 2025). Such interactions cultivate scientific argumentation, reasoning proficiency, and reflective thinking, which are integral components of scientific literacy.

Experiential Learning Theory

Kolb's (1984) experiential learning theory posits that learning is most effective when it involves a cyclical process of concrete experience, reflective observation, abstract conceptualization, and active experimentation. Experiential engagement facilitates deeper understanding and knowledge retention, particularly in domains requiring practical skills such as science (Nardito Mediana et al., 2025).

Student-led research embodies experiential learning by allowing students to actively design investigations, collect and analyze data, and reflect critically on outcomes. This hands-on engagement not only promotes mastery of scientific concepts but also develops reasoning and problem-solving skills, reinforcing the capacity to apply knowledge to novel contexts (Prudente & Antonio, 2023). The experiential approach thereby supports the cultivation of scientific reasoning and cognitive flexibility, which are essential for academic and professional success in science-related fields.

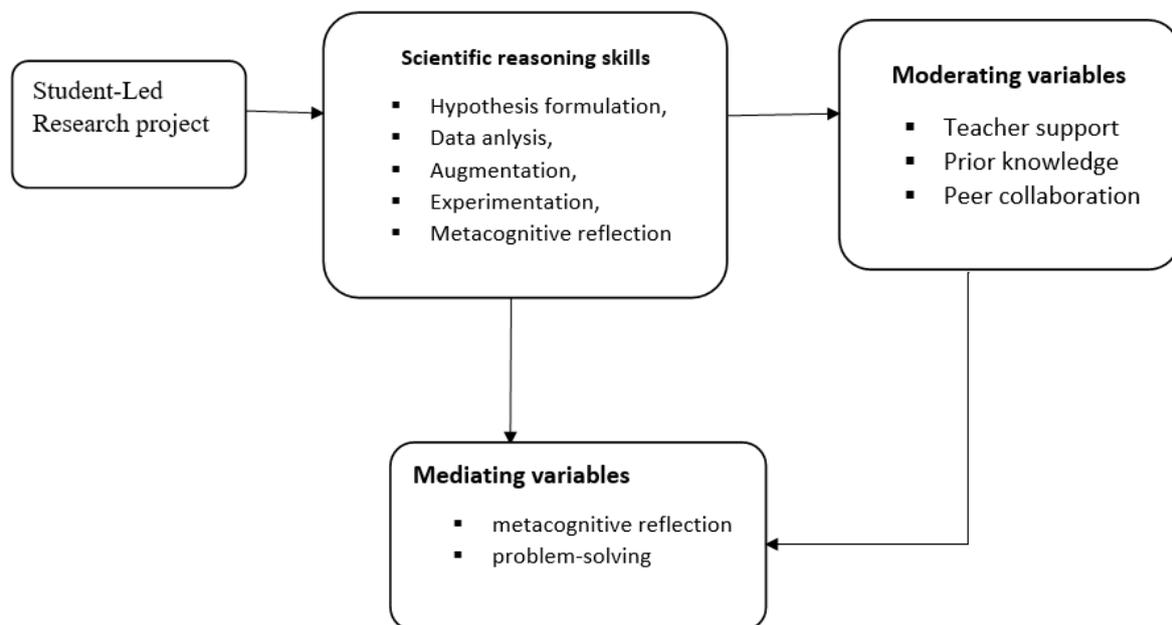
Integration of Theoretical Perspectives

Integrating constructivist, social-constructivist, and experiential learning frameworks provides a robust rationale for employing student-led research projects in science education. Constructivism explains how learners actively construct understanding through inquiry and reflection (Piaget, 1970). Social-constructivism emphasizes the importance of collaboration, peer dialogue, and scaffolding to advance reasoning skills (Vygotsky, 1978). Experiential learning highlights the significance of authentic, hands-on experiences for consolidating knowledge and promoting critical thinking (Kolb, 1984).

Collectively, these theoretical perspectives justify the pedagogical strategy of student-led research as an effective mechanism for enhancing scientific reasoning, critical thinking, metacognitive abilities, and problem-solving competencies. Furthermore, they inform instructional design by emphasizing the need to balance student autonomy with structured guidance, thereby maximizing the cognitive and practical benefits of research-based learning (Gomez, 2025; Arifin et al., 2025).

Conceptual Framework

The conceptual framework for this study is grounded in constructivist, social-constructivist, and experiential learning theories. It illustrates the anticipated relationships between the independent variable—student-led research projects—and the dependent variable—students' scientific reasoning skills. The framework also accounts for moderating and mediating variables that may influence this relationship, such as teacher support, prior knowledge, collaboration among peers, and metacognitive reflection.



Methodology

Research Paradigm and Design

This study was grounded in a pragmatic research paradigm, which prioritizes methodological flexibility and the use of approaches that best address the research problem. Pragmatism recognizes that complex educational phenomena—such as how student-led research projects influence scientific reasoning—are best understood through the integration of both numerical evidence and experiential accounts. In alignment with this paradigm, the study adopted a convergent parallel mixed-methods design, enabling quantitative and qualitative data to be gathered and analyzed simultaneously. This design supported a comprehensive understanding of both the measurable impact of student-led research projects and the contextual insights gained from students' lived experiences.

Population and Sampling

The study was conducted among Form Two science students in selected senior high schools in the Assin South District of Ghana's Central Region, where inquiry-based and research-oriented science instruction is routinely implemented. A total of 150 students were targeted for the quantitative component. To ensure a systematic and representative selection, a multi-stage sampling strategy was employed. First, schools were purposively selected based on their active engagement in student-led inquiry projects. Within these schools, students were stratified according to their academic programs, and 150 students were then randomly selected for the quantitative survey. For the qualitative phase, a smaller group of 20 students who demonstrated consistent participation and engagement in research activities was purposively chosen for in-depth interviews. This combined sampling approach ensured both statistical representativeness for quantitative analysis and rich, contextualized insights for qualitative interpretation.

Research Instruments

Data were collected using three complementary instruments designed to capture different dimensions of the inquiry process. Scientific reasoning was measured using an adapted form of *Lawson's Scientific Reasoning Test*, which evaluates proportional, correlational, probabilistic, and hypothetico-deductive reasoning. To document how students engaged in the inquiry tasks, an observational protocol captured behaviors related to hypothesis development, data handling, interpretation, and scientific argumentation. Qualitative insights were then obtained through a semi-structured interview schedule that explored students' perceptions, challenges, and reflective experiences as they conducted their research projects. Together, these instruments offered a multifaceted view of both performance and process.

Validity, Reliability, and Trustworthiness

Multiple strategies were applied to preserve the methodological rigor of the study. The quantitative instrument underwent expert validation to confirm content alignment with scientific reasoning constructs, while reliability was tested using Cronbach's alpha to ensure internal consistency. For the qualitative strand, the trustworthiness of findings was enhanced through member checking, peer debriefing, and the use of triangulated data sources. Detailed descriptions of the study context supported transferability, whereas an audit trail and reflexive documentation strengthened dependability and confirmability. These measures collectively increased the credibility and robustness of the findings.

Data Collection Procedures

Data collection was carried out in three distinct stages. In the first stage, students completed a pretest to determine their initial levels of scientific reasoning. During the main stage, they engaged in student-led research projects spanning several weeks, progressing through key phases such as selecting research topics, planning experiments, conducting investigations, and analyzing results. Throughout this period, students' inquiry behaviors and levels of engagement were carefully monitored. In the final stage, a posttest was administered to assess changes in scientific reasoning, and in-depth interviews were conducted with selected participants to capture detailed insights into their experiences, reflections, and challenges encountered during the research projects.

Quantitative data were analyzed using descriptive statistics and paired-samples t-tests to examine changes in students' scientific reasoning skills before and after the student-led research intervention. The analysis

focused on identifying the magnitude and significance of the observed improvements. Qualitative data were analyzed through thematic analysis, involving systematic coding of student responses and the identification of recurrent patterns. This process generated six main themes: enhanced scientific thinking, increased metacognitive reflection, strengthened argumentation skills, autonomy and ownership, collaboration and peer support, and resource and time constraints. An integrative interpretation of the findings was conducted, comparing and synthesizing results from both quantitative and qualitative strands to reveal how the intervention influenced scientific reasoning, student engagement, and learning experiences. This combined approach provided a comprehensive understanding of the outcomes and processes associated with student-led research activities

Ethical Considerations

The study adhered strictly to ethical research standards. Approval was obtained from the relevant institutional review committee, and consent was sought from school administrators, teachers, students, and parents where required. Participants were informed of the study's purpose, the voluntary nature of their participation, and their right to withdraw without penalty. Confidentiality was maintained through anonymized data handling and secure storage of all materials. These ethical precautions ensured that the research was conducted responsibly and with respect for participants' rights and welfare.

RESULTS

Quantitative Results

The quantitative phase explored the impact of student-led research projects on students' scientific reasoning skills. A paired-samples analysis was conducted to compare students' performance before and after the intervention. This comparison assessed whether participation in student-led research activities led to measurable gains in scientific reasoning.

Table 1. Pre-test and Post-test Results for Scientific Reasoning Skills

Variable	N	Mean (Pre- test)	SD (Pre- test)	Mean (Post- test)	SD (Post- test)	Mean Difference	t- value
Scientific Reasoning Skills	150	42.63	8.21	58.47	7.95	15.84	18.72

Note. $p < .001$

Following the analysis, results revealed a substantial improvement in students' scientific reasoning after participating in the student-led research projects. The mean score increased from 42.63 on the pre-test to 58.47 on the post-test, demonstrating a mean gain of 15.84 points. This difference was statistically significant, $t(149) = 18.72$, $p < .001$. The effect size (*Cohen's d* = 1.52) indicates a *very large practical effect*, confirming that student-led research projects had a strong and positive influence on students' scientific reasoning development

Qualitative Results

Qualitative data were analyzed using thematic analysis, generating six major themes describing students' experiences, challenges, and learning processes during the student-led research projects. These themes highlight the mechanisms underlying the quantitative gains in reasoning skills.

Table 2. Summary of Emergent Themes from Qualitative Analysis

Theme	Description
<i>Theme 1: Enhanced Scientific Thinking</i>	Students reported developing deeper reasoning skills through hypothesis formulation, designing experiments, and analyzing data.
<i>Theme 2: Increased Metacognitive Reflection</i>	Students became more aware of their thinking processes, planning steps, and evaluating their learning during the research projects.
<i>Theme 3: Strengthened Argumentation Skills</i>	Learners increasingly used evidence to justify conclusions and critique peers' interpretations.
<i>Theme 4: Autonomy and Ownership</i>	Students valued making independent decisions in selecting topics and methods.
<i>Theme 5: Collaboration and Peer Support</i>	Working in groups facilitated brainstorming, problem-solving, and shared responsibility.
<i>Theme 6: Resource and Time Constraints</i>	Students identified challenges such as inadequate materials, limited laboratory resources, and time pressure.

Key Qualitative Findings

Analysis of students' reflections revealed several consistent patterns. Learners described noticeable growth in their scientific thinking, particularly in how they formulated hypotheses, designed investigations, and interpreted data. They also reported heightened metacognitive awareness, noting that the projects prompted them to plan more deliberately, monitor their progress, and critically evaluate their own learning. Students further indicated improvements in argumentation, as they increasingly relied on evidence to support claims and assess peers' conclusions. Many expressed a stronger sense of autonomy, emphasizing the value of making independent choices during project design and execution. Collaborative work emerged as a supportive element, fostering idea sharing, joint problem-solving, and mutual encouragement. Despite these benefits, students identified persistent challenges, including limited resources, insufficient laboratory materials, and time constraints, which occasionally impeded the research process.

Integrated Mixed-Methods Findings

Quantitative and qualitative results were integrated using a joint display matrix, which synthesizes the statistical patterns with experiential insights. This integration demonstrates how the numerical improvements in scientific reasoning correspond with students’ lived experiences during the research process.

Research Question	Quantitative Results	Qualitative Themes	Integrated Interpretation
RQ1: Effect of student-led research projects on scientific reasoning	Students’ reasoning scores increased significantly after the intervention (Mean gain = 15.84; $t(149) = 18.72$, $p < .001$; $d = 1.52$), indicating a strong positive effect.	Students reported improved thinking, more reflective learning, and stronger use of evidence in explaining results.	The numerical gains align with students’ accounts, showing that authentic inquiry and reflective engagement were central to strengthening scientific reasoning.
RQ2: Students’ experiences and perceptions of the research projects	Observations showed high engagement (86%) and improvement in several reasoning subskills (78%).	Students appreciated autonomy, collaboration, and topic choice, though they noted challenges such as time limits and limited resources	Combining both strands suggests that active involvement and ownership supported learning, while resource constraints explain variation in students’ performance and experiences.

Table 1: Joint Display Integrating Quantitative and Qualitative Findings

Integrated Interpretation of Joint Display Findings

The integrated results show clear alignment between the quantitative gains in scientific reasoning and students’ qualitative accounts of their learning experiences. The significant improvement in test scores corresponds with students’ descriptions of developing stronger inquiry skills, becoming more reflective, and using evidence more effectively during investigations. This suggests that the student-led research activities created meaningful opportunities for authentic scientific thinking.

Students’ appreciation of autonomy, collaboration, and freedom in choosing topics also helps explain the high engagement levels observed quantitatively. These motivational factors appear to have supported the development of reasoning subskills across the intervention.

At the same time, qualitative reports of limited resources and time constraints provide insight into variations in individual performance. These contextual challenges may have restricted some students’ ability to fully benefit from the inquiry processes.

Overall, the merged findings indicate that student-led research projects enhanced scientific reasoning by promoting active participation and ownership of learning, while also highlighting structural barriers that need attention to optimize future implementation.

Discussion

The findings of this mixed-methods study demonstrate that student-led research projects significantly improved students' scientific reasoning skills and enriched their learning experiences. The quantitative results revealed a substantial and statistically significant increase in scientific reasoning scores following the intervention, indicating that students developed stronger abilities in hypothesis formulation, evidence evaluation, and logical interpretation. A substantial corpus of research affirms that inquiry-driven and learner-centered pedagogies are highly effective in cultivating higher-order cognitive competencies in science learning (Bybee, 2014; Lederman & Lederman, 2019). Kuhn (2010) argues that genuine scientific inquiry—anchored in prediction, experimentation, and argumentation—fosters the analytical reasoning essential for scientific literacy, and these features were embedded throughout the student-directed projects in this study.

The qualitative results offered deeper insight into the mechanisms underlying the observed gains. Students reported notable progress in their scientific reasoning, increased reflective engagement, and enhanced confidence in analyzing data—indicators of metacognitive advancement. These findings lend support to Zimmerman's (2002) assertion that environments promoting self-direction nurture strategic thinking and reflective self-monitoring. Students also highlighted the motivational value of autonomy in the project structure, explaining that having the freedom to select topics and design investigative strategies stimulated creativity and a strong sense of ownership. This aligns with self-determination theory, which posits that autonomy fosters intrinsic motivation and deeper learning (Deci & Ryan, 2000).

Collaborative learning experiences further shaped students' reasoning development. Peer discussions enabled learners to articulate ideas, refine interpretations, and jointly construct explanations—practices consistent with socio-constructivist learning theories (Vygotsky, 1978; Mercer, 2013). Such collaborative processes likely supported improvements in reasoning subskills, echoing prior evidence that dialogic engagement strengthens scientific argumentation and conceptual growth (Crawford, 2014).

However, the data also revealed contextual factors that accounted for variations in student outcomes. Learners described challenges linked to limited laboratory resources, inadequate materials, and tight instructional schedules. These constraints—common in under-resourced science education contexts—can hinder iterative experimentation and reduce the depth of inquiry-based learning (Anamuah-Mensah & Andoh, 2010). Consequently, ensuring sufficient logistical support is crucial for maximizing the benefits of student-led investigations.

Overall, the integration of quantitative and qualitative findings demonstrated clear convergence. The statistically significant gains in reasoning ability were consistent with learners' accounts of strengthened inquiry thinking, more deliberate reflection, and greater confidence in using evidence. Likewise, the observed high engagement corresponded with students' positive perceptions of autonomy and collaboration. Creswell and Plano Clark (2018) observe that such convergence enhances the interpretive strength of mixed-methods research by revealing how learning processes translate into measurable outcomes

The qualitative themes also explained why some students advanced more than others, with resource and time limitations offering contextual insights into differential achievement patterns.

Implications of the Study

The outcomes of this study present several key implications for science education policy, classroom practice, curriculum development, and future scholarship. The notable enhancement in students' scientific reasoning following participation in student-driven research activities underscores the effectiveness of inquiry-based pedagogies in building higher-order thinking skills. This finding affirms longstanding assertions that meaningful engagement in authentic scientific processes—such as experimentation, argumentation grounded in evidence, and continual reflection—nurtures the reasoning proficiencies essential for scientific literacy (Kuhn, 2010; Lederman & Lederman, 2019; Bybee, 2014).

On the instructional front, the results suggest that granting learners autonomy in selecting research questions and determining investigative approaches can boost motivation, curiosity, and the overall quality of engagement. This aligns with the principles of self-determination theory, which posits that autonomy strengthens persistence, effort, and deep conceptual learning (Deci & Ryan, 2000). Accordingly, teachers are encouraged to incorporate more student-led inquiry tasks while providing supportive scaffolding that guides reasoning without diminishing independence.

The findings also reaffirm the importance of collaboration in advancing students' reasoning abilities. The qualitative data showed that peer discussions, shared problem-solving, and collaborative interpretation of results enabled students to articulate, negotiate, and refine their scientific explanations. These observations reflect socio-constructivist perspectives, which emphasize the role of social interaction in developing scientific understanding (Vygotsky, 1978; Mercer, 2013). Schools should therefore promote cooperative learning structures that encourage rich scientific dialogue and collaborative argumentation.

In terms of curriculum and policy, the evidence supports the integration and expansion of project-based inquiry within national science programs. Although many contemporary curricula advocate inquiry-centered learning, implementation challenges persist, particularly in contexts with limited resources. The constraints highlighted in this study—such as inadequate laboratory materials, insufficient equipment, and restricted instructional time—mirror issues documented in research from under-resourced educational environments (Anamuah-Mensah & Andoh, 2010). To sustain the positive outcomes observed, policymakers must invest in science infrastructure, supply consumable materials, and strengthen teacher preparation in inquiry pedagogy.

The study also offers important directions for future research. The alignment between quantitative gains and qualitative insights demonstrates the value of mixed-methods approaches for illustrating both learning outcomes and the processes that shape them (Creswell & Plano Clark, 2018). Further investigations should examine how different types of instructional support—such as teacher scaffolding, peer tutoring, or digital inquiry platforms—affect students' reasoning within student-led project settings.

Limitations and delimitations

The study's limitations and delimitations should be acknowledged in interpreting the findings. The research was limited to a sample of 150 senior secondary school students from selected schools, which may restrict the generalizability of the results to other educational levels or regions. The use of researcher-developed

instruments, although validated, may also introduce measurement bias, while the relatively short duration of the intervention may not fully capture long-term development of scientific reasoning. Contextual challenges such as limited laboratory resources and time constraints may have influenced the depth of students' inquiry engagement. Delimitations were intentionally set to maintain focus, including the decision to examine only scientific reasoning rather than broader scientific competencies, and to concentrate on student-led research projects as the primary instructional strategy. The study also delimited data collection to pre- and post-tests, interviews, and classroom observations, excluding perspectives from teachers or school administrators. These boundaries allowed the study to remain manageable and aligned with its core purpose, but they also narrow the interpretive scope of the findings.

Conclusion and Recommendations

Conclusion

This study provides compelling evidence that student-led research projects significantly enhance students' scientific reasoning skills and deepen their engagement in scientific inquiry. The substantial improvement in test scores, supported by rich qualitative accounts, demonstrates that active involvement in designing and conducting investigations promotes higher-order thinking, metacognitive reflection, and evidence-based argumentation. Students' appreciation of autonomy, collaboration, and authentic inquiry experiences further illustrates the pedagogical value of positioning learners as active constructors of scientific knowledge. At the same time, contextual challenges—particularly limited resources and time constraints—highlight the need for supportive learning environments to ensure equitable access to high-quality inquiry experiences. Overall, the study reinforces the growing consensus that embedding student-led investigations within science curricula is an effective strategy for cultivating scientific literacy and preparing learners for advanced scientific thinking.

Recommendations

1. Ministry of Education should strengthen laboratory resourcing to ensure that schools have adequate materials, equipment, and consumables required for meaningful inquiry-based instruction.
2. Curriculum developers should integrate student-led research projects more explicitly into science syllabi, providing structured guidance that encourages autonomy while ensuring alignment with learning standards.
3. School administrators should allocate sufficient instructional time for extended investigations, allowing students to engage fully in the iterative processes of scientific inquiry.
4. Teachers should adopt scaffolding strategies that support hypothesis formulation, data interpretation, and reflective thinking without limiting student independence.
5. Teacher education institutions should incorporate inquiry-based pedagogical training, equipping pre-service and in-service teachers with the skills needed to facilitate student-led research effectively.
6. Future researchers should conduct longitudinal studies to examine the sustained impact of student-led inquiry on scientific reasoning and to explore variations across different school contexts.

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