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Investigating the effectiveness of inquiry-based learning (IBL) on students' academic achievement

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Abstract

This study investigates the effectiveness of IBL on students' academic achievement within an undergraduate education context. A quasi-experimental, pre-test–post-test control group design was employed, involving 60 second-year students assigned to either an IBL-based instruction group or a traditional lecture-based instruction group. Academic achievement was measured using a validated multiple-choice test aligned with the course objectives. Analysis of covariance (ANCOVA) results indicated that the students who were exposed to inquiry instruction performed significantly better than the students of the traditional instruction group with a very large effect size, though these results need to be interpreted cautiously due to unusually high values obtained. Furthermore, prior academic achievement emerged as a strong predictor of post-test performance. These findings highlight the considerable potential of inquiry-based learning to advance academic outcomes and reinforce the importance of initial learner preparedness. The study concludes by recommending broader adoption of structured inquiry models, such as the 5E learning cycle, while calling for future research to explore long-term effects and individual learner differences.

Introduction

In the 21st century, education systems are increasingly challenged to cultivate learners who are critical thinkers, problem-solvers, and lifelong investigators. Against the backdrop of rapid technological advancements and information proliferation, the focus of effective teaching has shifted from transmitting static knowledge to nurturing inquiry-oriented learning environments (Karamustafaoğlu, 2010). IBL, grounded in the constructivist paradigm, emerges as a prominent pedagogical approach designed to equip students with the cognitive skills necessary for navigating complex, dynamic societies. IBL shifts the locus of learning from teacher-directed instruction to student-centred exploration, where learners formulate questions, investigate phenomena, evaluate evidence, and construct knowledge collaboratively (Bransford, Brown, & Cocking, 2000). This approach contrasts with traditional models that often reduce students to passive recipients of information, diminishing opportunities for critical engagement and deeper understanding (Stofflett, 1998; VAST, 1998). The structured engagement inherent in models such as the 5E learning cycle (Bybee et al., 2006) underscores the theoretical robustness and practical applicability of inquiry-based methodologies across educational levels and disciplines.

Research has consistently shown that IBL can enhance students' academic achievement by developing scientific reasoning, promoting active participation, and supporting higher-order thinking skills (Abdi, 2014; Akpullukçu, 2011; Kaçar et al., 2021). Meta-analyses and experimental studies suggest that learners exposed to inquiry-based environments outperform their peers taught through traditional methods, with notable gains observed particularly in science, social studies, and mathematics (Cairns & Areepattamannil, 2019; Kaçar et al., 2021). Despite strong theoretical and empirical support, the degree to which IBL improves academic achievement relative to traditional instruction, and the extent to which prior academic performance moderates this relationship, remains a pertinent question, particularly in undergraduate education settings. Addressing these gaps is crucial for refining pedagogical practices and informing curriculum design.

Literature review

In the contemporary era marked by rapid advancements in information and technology, the role of science and technology education is paramount in shaping future societies (Karamustafaoğlu, 2010). Science education has long been guided by the goal of developing students' scientific literacy (Rubba & Andersen, 1978; Hurd, 1970; Klopfer, 1971), with instructional methods playing a critical role in achieving this objective (Baez, 1971). Among the various pedagogical approaches, inquiry-based learning has emerged as a prominent and research-supported strategy.

Inquiry-based science education engages learners in the authentic processes of scientific inquiry and knowledge construction (Bransford, Brown, & Cocking, 2000). This method contrasts with traditional instruction by shifting from teacher-centred delivery of factual content to student-centred exploration and problem-solving. Secker (2002) highlights that inquiry-based instruction captures student interest, fosters the use of laboratory techniques, encourages logical problem-solving, supports extended exploration, and promotes evidence-based scientific writing. Sandoval and Reiser (2004) argue that such instruction requires building a classroom community of practice akin to that of professional scientists, where students experience knowledge construction and justification firsthand. Traditional classroom models, in contrast, often reduce learners to passive recipients of fixed bodies of knowledge, leaving little room for questioning, critical thinking, or student interaction (Stofflett, 1998; VAST, 1998). Even when practical activities are included, they may fail to stimulate concept exploration or meaningful discussion, thus missing the core of scientific literacy and critical inquiry (Yore, 2001). Moreover, teacher-centred methods assume uniform prior knowledge and learning pace among students, which may hinder meaningful engagement and comprehension (Lord, 1999).

Inquiry-based learning can take multiple forms, ranging from structured to open inquiry (Bülbül, 2010). Structured inquiry involves guided investigations designed to teach specific content, leading to more autonomous open inquiry. One structured model grounded in Piagetian cognitive theory is the Learning Inquiry Cycle (Bevevino, Dengel, & Adams, 1999), further developed into the widely adopted 5E instructional model (Cavallo & Laubach, 2001; Settlage, 2000). The 5E learning cycle—developed by Bybee et al. (2006)—comprises five phases: Engagement, where prior knowledge is elicited and curiosity sparked; Exploration, where students participate in shared activities to uncover and address misconceptions; Explanation, which focuses on conceptual understanding and teacher-facilitated instruction; Elaboration, allowing learners to apply concepts to new situations; and Evaluation, involving formal and informal assessments of student learning and feedback provision. This cyclical model aligns with the inquiry nature of science and natural student learning processes, making it a robust framework for inquiry-based instruction.

Inquiry-based learning and academic achievement

IBL is widely recognised as a student-centred strategy rooted in the constructivist learning paradigm. The concept of "inquiry" itself has evolved beyond mere questioning or investigation. While the Turkish Language Association (TDK, 2020) defines inquiry as questioning, Kartal (2014) expands it to include observation, preliminary evaluation, and source-based investigation. Güneş (2014) further frames it as a cognitive process that promotes changes in mental structure, allowing learners to engage in deeper thinking, problem-solving, and independent use of information. Within this framework, IBL plays a vital role in modern education, as it equips learners at all levels with essential cognitive and scientific competencies. IBL facilitates environments where learners formulate questions, identify hypotheses, gather data, and analyse findings through scientific methods (Güneş, 2014; Kartal, 2014). As Hırça (2014) notes, it empowers learners to take ownership of their education by encouraging them to solve real-world problems actively and thoughtfully. Çalışkan (2017) views IBL as a process where learners are presented with complex situations requiring collaborative inquiry and solution-testing. Sözen (2010) also highlights IBL's potential to support critical thinking and problem-solving through meaningful questioning.

Meta-analytic research on IBL conducted in Turkey between 2000 and 2020 shows that IBL significantly enhances academic achievement across disciplines, including science, arts, social studies, foreign languages, and mathematics (Abdi, 2014; Akpullukçu, 2011; Altunsoy, 2008; Bilir & Özkan, 2018; Çelik, 2012; İlter, 2013; Kaya & Yılmaz, 2016; Kaçar, 2020). Kaçar et al. (2021) compiled 30 theses and articles to investigate IBL's impact, concluding that its application at the high school level has the highest effect size on student achievement. The findings also revealed no significant differences in outcomes between dissertations and published articles. IBL is not a monolithic strategy but encompasses several key features that make it universally applicable across education levels. Cairns and Areepattamannil (2019) summarise its core principles as: (1) engaging students with scientifically oriented questions, (2) encouraging the use of evidence for explanation development, (3) supporting student-derived explanations, (4) allowing for the evaluation of multiple viewpoints, and (5) promoting scientific communication. Scholars such as Karamustafaoğlu and Havuz (2016) emphasise that IBL sharpens learners' mental skills and problem-solving abilities by fostering meaningful learning experiences. Similarly, Ernst et al. (2017) define IBL as a dynamic form of active learning adaptable to different educational contexts. Lee and Songer (2003) argue that IBL allows students to internalise the nature of scientific inquiry by engaging in processes that mirror real-world scientific investigation. Students work collaboratively, develop critical thinking, and use digital technologies for research and presentation, thereby enhancing digital and scientific literacy. The concept of literacy itself is evolving. According to Kurudayıoğlu and Tüzel (2010), literacy involves structuring, classifying, and interpreting various types of information, especially digital and electronic. Aytaş and Kaplan (2017) similarly define literacy as an increasingly field-specific skill that demands focused, goal-oriented learning. In this light, IBL supports the development of information, internet, and scientific literacy, positioning learners for success in knowledge-intensive environments. Thus, this study is sought to answer these two questions:

1: To what extent does inquiry-based learning improve students' academic achievement compared to traditional instruction?
2: To what extent does prior academic performance influence the effect of inquiry-based learning on achievement?

Methodology

Research design

This study employed a quasi-experimental, pre-test–post-test control group design to evaluate the effectiveness of IBL on students' academic achievement. This design is appropriate when random assignment is not feasible but control over confounding variables is necessary (Creswell & Guetterman, 2019). Two intact classes were used: one assigned to the experimental condition (IBL instruction) and the other to the control condition (traditional lecture-based instruction). Initial group differences were statistically controlled using analysis of covariance (ANCOVA), with pre-test scores serving as a covariate.

Participants

Participants were 60 second-year undergraduate students (N = 60), enrolled in an introductory education course at a public university in China. They were drawn from two intact classes of approximately 30 students each. Due to institutional scheduling constraints, a convenience sampling strategy was employed by selecting two available classes that were comparable in terms of course content, instructional time, and class size. The university is situated in a province known for its reputable higher education institutions, including universities that offer PhD programs in education and English teaching. See Table 1 and Figure 1.

Table 1

Between-Subjects Factors

		N
Group	Control	30
	Experimental	30

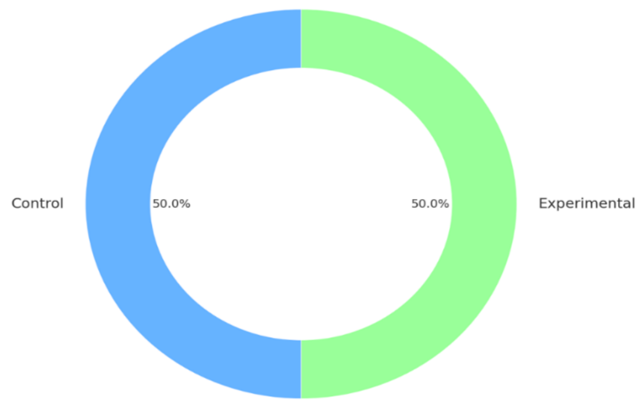

Figure 1
Participant allocation: Control vs Experimental

Both groups were taught by instructors with over five years of university-level teaching experience. Instructors were briefed to follow only the assigned instructional method throughout the six-week intervention. Baseline academic data, including cumulative grade point averages (GPAs), indicated comparability between the groups. Each class received equal contact time, with two 90-minute sessions per week.

Materials

Academic achievement was assessed using a 40-item multiple-choice test developed to align with the course's intended learning outcomes. Items targeted three cognitive domains—recall, comprehension, and application—based on Bloom's revised taxonomy. The test's content validity was confirmed by three subject-matter experts who reviewed the items for clarity, relevance, and coverage of course content. Necessary revisions were incorporated based on their feedback. To establish internal consistency reliability, the test was piloted with a group of 15 second-year students from a different class who were not part of the main study. These students had completed the same course in a previous semester. Pilot test data were analysed using Cronbach's alpha, resulting in a reliability coefficient of .82, which is considered acceptable for research purposes (Taber, 2018). The final version of the test used in the study was based on expert validation and pilot testing. Although students' engagement with the instructional methods was measured using a separate scale, those results fall outside the scope of this report and are therefore not discussed here.

Procedure

The intervention spanned six weeks, with each group receiving twelve 90-minute sessions (two per week). In the first week, both groups completed a pre-test under standardised conditions. The experimental group received instruction through the 5E instructional model (Engage, Explore, Explain, Elaborate, Evaluate), which promoted inquiry through collaborative learning, group discussions, problem-solving tasks, and digital learning tools such as concept mapping and interactive simulations. In contrast, the control group received traditional lecture-based instruction, involving teacher-led explanations, textbook-based learning, and individual note-taking, supported by slide presentations. In the final week, both groups completed the post-test. All test scripts were anonymised before scoring to reduce bias, and only complete cases (N = 60) were retained for statistical analysis.

Data analysis

Quantitative data were analysed using SPSS version 29. Descriptive statistics (means and standard deviations) were calculated for both groups. To assess the effectiveness of IBL while controlling for initial differences, an ANCOVA was conducted. The dependent variable was the post-test score, the independent variable was the instructional method (IBL vs. traditional), and the covariate was the pre-test score as shown in Table 2.

Table 2

Descriptive Statistics

Dependent Variable: Post-test score

Group	Mean	Std. Deviation	N
Control	65.97	2.025	30
Experimental	82.47	2.113	30
Total	74.22	8.569	60

The analysis of covariance (ANCOVA) presented in Table 3 examined the effect of instructional method on students' post-test scores while controlling for pre-test performance. The results showed a statistically significant main effect of the instructional method, $F(1, 57) = 3552.554$, $p < .001$, with a partial eta squared of .984, indicating a very large effect size. Students in the IBL group significantly outperformed those in the lecture-based control group. Additionally, the covariate (pre-test score) was a significant predictor of post-test performance, $F(1, 57) = 519.044$, $p < .001$, partial eta squared = .901, confirming the substantial influence of students' initial academic achievement on their final scores.

As shown in Table 3, the overall model was statistically significant, $F(2, 57) = 4994.035$, $p < .001$, accounting for 99.4% of the variance in post-test scores ($R^2 = .994$). While these values suggest a powerful instructional impact of IBL, the exceptionally high F-values and effect sizes warrant cautious interpretation, as such magnitudes are uncommon in educational intervention research and may reflect minimal within-group variability or small error variance. Nevertheless, the findings provide compelling evidence in support of inquiry-based learning as an effective pedagogical strategy for improving academic outcomes in undergraduate education.

Table 3

Tests of Between-Subjects Effects

Dependent Variable: Post-test score

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	4307.601[a]	2	2153.800	4994.035	.000	.994
Intercept	8.675	1	8.675	20.115	.000	.261
Pretestscore	223.851	1	223.851	519.044	.000	.901
Group	1532.126	1	1532.126	3552.554	.000	.984
Error	24.583	57	.431			
Total	334819.000	60				
Corrected Total	4332.183	59				

a. R Squared = .994 (Adjusted R Squared = .994)

Ethical considerations

Ethical approval for the study was granted by the university's Institutional Review Board (IRB) in China, and the study adhered to both the university's ethical standards and the British Educational Research Association (BERA) ethical guidelines (2018). Participants provided written informed consent after receiving information about the study's purpose, procedures, and voluntary nature. Confidentiality was assured, and participants were informed of their right to withdraw at any time without penalty. No incentives were provided.

Discussion

This study's results offer strong empirical evidence for the learning outcome benefits of IBL. The statistically significant differences between the experimental group and the control group, as evidenced by both mean post-test scores and large effect sizes, ring true with other published work that promotes inquiry as an optimal method of instruction in science education more generally. This discussion follows by considering how the current results extend, support, or develop the theoretical and empirical foundations laid by previous studies of IBL.

Analysis of covariance revealed that students' post-test scores were significantly higher for students who learned through IBL than for students who learned using traditional methods, even controlling for students' past academic achievement. This finding is consistent with the contention made by Abdi (2014), Akpullukçu (2011), and Kaçar et al. (2021) that students' performance is significantly higher due to IBL across different subject matters and levels of education. The large effect size observed for this study (partial eta squared = .984) may at first glance look abnormally large, but it is consistent with Kaçar et al.'s (2021) meta-analytic finding that high school and undergraduate settings are highly receptive to inquiry-based interventions. This finding could be an indication of the compatibility between students' learning preparedness at this level and the constructivist demands placed by IBL. The application of the 5E learning model—embracing engagement, exploration, explanation, elaboration, and evaluation—offered an organised but adaptable framework for student-focused learning, following the ideas of Bybee et al. (2006) and of Cavallo and Laubach (2001). Such authors suggest that the 5E approach reflects the way things are learned by natural means, as with scientific inquiry, leading students to learn scientific concepts more profoundly than otherwise. The outcome of the current research, an increase of over 16 points of mean achievement score for the experimental group, is consistent with theirs, demonstrating the applicability of the 5E approach to learning content as well as the development of scientific reasoning. This gain in achievement can be understood via cognitive interpretation, too. Inquiry learning environments require active engagement with hypothesis development, data analysis, and evidence-based argumentation—all known to increase understanding and learning transfer (Bransford et al., 2000). The students participating in the group with IBL were more likely to have been cognitively active as a result of these processes, to the extent that this could have led to their better performance. The use of digital functionalities and interactive simulation, as utilised by the study, is also consistent with Ernst et al.'s (2017) argument that IBL is an active form of learning that is flexible, dynamic, and able to combine contemporary technological tools. Such integration was potentially able to increase the students' learning process and achievement by enabling engagement via multiple channels.

In addition, the strong pre-test predictive relationship to post-test results ($F = 519.044$, $p < .001$) is evidence supporting previous work by Kaya and Yılmaz (2016) who underscored that students' earlier academic ability has the potential to shape the extent to which students gain from constructivist practices. Although much is said about the ability of IBL to personalise and democratise learning (Güneş, 2014; Kartal, 2014), it is never done in isolation. Students coming to the learning arena with greater initial knowledge perhaps move through the inquiry cycle more quickly, ask more sophisticated questions, and gain greater understanding through collaborative and reflective segments. As such, while overall effective, the effect of IBL is potentially mediated by students' initial preparedness. The problem-solving and joint-working aspects of IBL, prioritised at the elaboration stage of the 5E cycle, have arguably played an important role in gains in achievement as well. As Çalışkan (2017) suggests, exposing learners to rich, realistic scenarios that demand collective thought promotes extended engagement and long-term persistence. The desirable effects of the group work under the IBL potentially capture not only the depth of engagement cognitively but also the learning socio-cognitively that comes along with inquiry tasks. As Secker (2002) and Sandoval and Reiser (2004) posit, the shared nature of inquiry develops the learning culture of the classroom to be reflective of professional methods of scientific practice. Such an educational setting may promote feedback that is bidirectional, challenge assumptions, and deepen explanatory reasoning, all of these to promote development at the academic level. Additionally, the results contradict the continued use of teacher-centred models, which, as proposed by Stofflett (1998) and Yore (2001), tend to suppress critical thought and turn learners into passive receivers of knowledge. Conversely, students within the IBL group constructed knowledge actively by asking questions, carrying out investigations, and creating explanations independently. The shift from passive to active learner is the hallmark of constructivist pedagogy and is at the heart of contemporary accounts of academic literacy, which now encompass the power to organise and analyse digital, scientific, and informational texts (Kurudayıoğlu & Tüzel, 2010; Aytaş & Kaplan, 2017).

This literacy development is supported by the overall objectives of IBL to advance scientific and technological competency, according to Lee and Songer (2003). The utilisation of computer-based simulations and concept maps in this study potentially enhanced not only content learning but the learning of higher-order skills like data interpretation and argumentation, critical skills in contemporary knowledge communities. This is evidence that IBL is more than an educational delivery strategy but an arena where multifaceted literacy as well as lifetime learning skills are cultivated. Notably, this research upholds the context-sensitive and scalable nature of IBL. As noted by Cairns and Areepattamannil (2019), inquiry-based instruction is more than the use of open questions; it necessitates leading students to compare numerous views, validate claims with evidence, and conduct scientific communication. The current intervention, over the course of only six weeks, recorded significant learning gains, indicating that even short durations of applying IBL, provided it is properly organised, can have great advantages. This upholds the scalability of IBL across varied academic calendars and classrooms.

Even so, the results are to be viewed with some reservation. The large effect sizes and F-values may indicate a ceiling effect, limited within-group variance, or inflated results as a result of the small sample size ($N = 60$) and short treatment period. As Cohen (1988) cautions, these large values, statistically valid though they may be, might suppress the nuances to be found by larger, more diverse samples. In the future, longitudinal designs and mixed methods studies must be used to investigate the influence of IBL on achievement, attitudes, motivation, and persistence over time. In addition,

even though this investigation came to control for past academic achievement, it did not investigate the interactions of other variables—gender, learning styles, or epistemological beliefs—with inquiry-based instruction. According to Lord (1999), constructivist methods are especially attuned to differences among individual students. It is possible that some subpopulations within the treatment class gained to a greater extent than others, but the current study did not investigate along these axes. Disaggregated analysis might offer greater understanding of who gains the most from IBL and why.
Another significant limitation is overdependence upon multiple-choice testing as indicators of academic accomplishment. Such testing is objective and efficient but cannot capture the conceptual depth or process gains prioritised through inquiry learning. Scientific reasoning, communication, and metacognition, such areas that tend to be peripheral to traditional assessments, are given merit by Yore (2001). In future assessments, students' performance tasks, reflective journals, or oral presentation could be included to triangulate learning to capture the comprehensive nature of IBL.
In spite of these constraints, the research is an important contribution to the debate about effective higher education pedagogy. It is an extension of the theoretical work by Bransford et al. (2000) and Sandoval and Reiser (2004), who position learning as an activity of knowledge building enabled by inquiry and social interaction. By placing the intervention into a quasi-experimental context, the research lends causal status to assertions about the success of IBL. Further, it is an endorsement that inquiry-oriented practices, particularly those organised around models such as the 5E cycle, can exceed conventional lecture-based approaches to fostering academic achievement. The findings highlight the power for transformation that inquiry-based learning can bring to undergraduate education. By promoting critical thought, scientific argument, and active participation, IBL not only enhances academic achievement but also better prepares students for the demands of contemporary scientific and professional work. The conclusions support the increasing consensus among education researchers that inquiry is not an alternative to conventional instruction but an evolution toward more purposeful and enduring learning. The longitudinal effects of IBL, the transfer of IBL to other fields, and the intersection of IBL with individual learner traits remain to be explored through future research. The data are unambiguous: when students are invited to inquire, investigate, and reason, they don't merely learn—they flourish.

Conclusion

This study provides compelling evidence that IBL significantly enhances students’ academic achievement compared to traditional lecture-based instruction. Students who engaged in the structured inquiry approach demonstrated markedly higher post-test scores, even when controlling for prior academic performance. These findings affirm that IBL, particularly when organised around frameworks such as the 5E learning cycle, creates dynamic and student-centred environments that encourage critical thinking, problem-solving, and deeper conceptual understanding. Moreover, the strong predictive relationship between prior academic achievement and post-test outcomes suggests that although IBL benefits all learners, its effect may be amplified for students with stronger academic foundations. This highlights the need for differentiated instructional strategies within inquiry-based settings to ensure that all learners can fully benefit from the approach. While the findings are robust, caution must be exercised due to the limited sample size and short intervention period. Future studies should adopt longitudinal and mixed-methods designs to capture the enduring effects of IBL and to better understand how individual learner characteristics influence inquiry-based outcomes. Expanding assessment beyond multiple-choice testing to include performance tasks and reflective practices is also recommended. Ultimately, this research strengthens the case for moving beyond traditional didactic teaching towards inquiry-based pedagogies that better prepare students for the cognitive demands of contemporary knowledge societies. By cultivating active inquiry, scientific reasoning, and collaborative learning, IBL offers a pathway to more meaningful, lasting educational achievement. While the findings affirm the potential of IBL, the conclusions are specific to the sample studied and should be generalised to broader contexts with caution. Larger and more diverse samples are recommended for future research.

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Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this study.

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