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Enhancing mathematical problem solving through inquiry based learning: a quasi experimental study in higher education

Mejora de la resolución de problemas matemáticos mediante el aprendizaje basado en la indagación: un estudio cuasiexperimental en educación superior

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RESUMEN

La resolución de problemas matemáticos constituye una competencia fundamental en la educación superior; sin embargo, los estudiantes universitarios suelen presentar dificultades para transferir los conocimientos matemáticos a problemas no familiares y contextualizados. Este estudio examinó el desempeño en la resolución de problemas matemáticos mediante el aprendizaje basado en la indagación guiada (IBL, por sus siglas en inglés) y la enseñanza convencional basada en clases magistrales, utilizando un diseño cuasiexperimental de pretest y posttest con un grupo de comparación no equivalente. Los resúmenes agregados disponibles indican que el grupo IBL pasó de una media de $M = 5,21$ ($DE = 1,12$) en el pretest a $M = 8,34$ ($DE = 0,98$) en el posttest, lo que representa un incremento medio aritmético de 3,13 puntos. El grupo de comparación pasó de $M = 5,18$ ($DE = 1,15$) a $M = 6,02$ ($DE = 1,20$), con un incremento de 0,84 puntos; las medias registradas en el posttest difirieron en 2,32 puntos. Debido a que no fue posible recuperar la base de datos original a nivel individual ni el número exacto de participantes incluidos en los análisis, no se realizó un nuevo análisis inferencial y no se conservaron los estadísticos t ni los tamaños del efecto estandarizados reportados previamente. Por tanto, los hallazgos se interpretan como evidencia descriptiva y específica del contexto de una mayor mejora observada mediante el IBL guiado, y no como una prueba causal definitiva. El estudio destaca el valor potencial de la indagación estructurada y subraya la importancia de una presentación transparente de los resultados y de una gestión reproducible de los datos en la investigación educativa cuasiexperimental.

Palabras clave: aprendizaje basado en la indagación; resolución de problemas matemáticos; educación superior; diseño cuasiexperimental; aprendizaje activo.

ABSTRACT

Mathematical problem-solving is a core competence in higher education, yet university students often experience difficulty transferring mathematical knowledge to unfamiliar and contextualized problems. This study examined mathematical problem-solving performance under guided inquiry-based learning (IBL) and conventional lecture-based instruction using a quasi-experimental pretest-posttest design with a non-equivalent comparison group. The retained aggregate summaries indicate that the IBL group changed from $M = 5.21$ ($SD = 1.12$) at pretest to $M = 8.34$ ($SD = 0.98$) at posttest, an arithmetic mean increase of 3.13 points. The comparison group changed from $M = 5.18$ ($SD = 1.15$) to $M = 6.02$ ($SD = 1.20$), an increase of 0.84 points; the archived posttest means differed by 2.32 points. Because the original individual-level database and exact analytic sample counts could not be recovered, no new inferential reanalysis was undertaken, and previously reported t statistics and standardized effect sizes were not retained. The findings are therefore interpreted as descriptive, context-specific evidence of a larger observed improvement under guided IBL rather than as definitive causal proof. The study highlights the potential value of structured inquiry while underscoring the importance of transparent reporting and reproducible data management in quasi-experimental educational research.

Keywords: inquiry-based learning; mathematical problem-solving; higher education; quasi-experimental design; active learning.



1. INTRODUCCIÓN

Mathematical problem-solving is a central outcome of university education because it requires students to interpret information, identify relationships, select and justify strategies, monitor solution processes, and evaluate the plausibility of results. These processes extend beyond procedural fluency. They involve conceptual understanding, strategic flexibility, metacognition, and the ability to transfer knowledge to unfamiliar situations. In higher education, these competencies are especially important for future teachers, who must not only solve problems but also explain mathematical reasoning, anticipate alternative strategies, and support learners who approach the same problem in different ways. International evidence continues to show persistent difficulties in mathematical reasoning and the application of knowledge, reinforcing the need to examine instructional approaches that move beyond routine demonstration and repetition (OECD, 2023).

Conventional lecture-based instruction can be efficient for presenting definitions, algorithms, and examples, particularly when students are encountering new or technically demanding material. However, a predominantly transmissive approach may offer limited opportunities for learners to formulate questions, test conjectures, compare alternative solution paths, and articulate the reasoning underlying their decisions. Research on active learning has shown that student performance in science, technology, engineering, and mathematics can improve when learners are required to engage cognitively with course content rather than remain primarily passive recipients of explanations (Freeman et al., 2014). The educational implication is not that direct instruction should be abandoned, but that its use may be strengthened when combined with structured opportunities for exploration, explanation, feedback, and reflection.

Inquiry-based learning (IBL) represents one such approach. IBL organizes learning around questions, problems, evidence, reasoning, and the progressive construction or refinement of explanations. The inquiry cycle commonly includes orientation to a problem, conceptualization, investigation, interpretation, and discussion or reflection (Pedaste et al., 2015). In mathematics, these phases can be adapted so that students examine a problem situation, identify what is known and unknown, propose relationships or hypotheses, attempt multiple strategies, compare representations, justify results, and revisit initial assumptions.



This structure is compatible with mathematical problem-solving because both inquiry and problem-solving require uncertainty to be managed through reasoning rather than through immediate reproduction of a known procedure.

The effectiveness of inquiry depends strongly on the amount and quality of guidance. Meta-analytic evidence indicates that inquiry-based learning tends to produce stronger outcomes when learners receive appropriate scaffolding, prompts, process constraints, explanatory feedback, or other forms of instructional support (Lazonder & Harmsen, 2016). Similarly, studies of discovery-oriented instruction show that minimally guided discovery is less reliable than forms of discovery that include feedback, worked guidance, or structured prompts (Alfieri et al., 2011). This distinction is particularly important in university mathematics. Students can benefit from intellectual autonomy, but unguided exploration may create excessive cognitive demands or allow misconceptions to persist. Guided IBL therefore seeks a balance: learners are expected to make decisions and justify reasoning, while the instructor provides enough structure to keep the inquiry mathematically productive.

This balance is also consistent with cognitive perspectives on learning. Learners have limited working-memory capacity, and instructional designs that introduce too many interacting elements without adequate structure can interfere with learning (Mayer, 2020). Critiques of minimally guided instruction have therefore emphasized the need for explicit support, especially for novices (Kirschner et al., 2006). At the same time, inquiry-oriented approaches can provide productive cognitive challenges when students possess sufficient prior knowledge and when tasks are sequenced carefully. The purpose of guidance is not to remove intellectual effort, but to focus that effort on meaningful reasoning, explanation, and transfer. In this sense, well-designed inquiry can combine the strengths of explicit instruction with opportunities for independent mathematical thinking.

Mathematical problem-solving itself is a complex, iterative process. Schoenfeld (1985) emphasized that successful problem solvers draw not only mathematical knowledge but also on heuristics, monitoring, beliefs, and decisions about how to allocate attention. Classroom instruction influences these dimensions through the kinds of tasks students encounter and the discourse that surrounds them. When students are routinely asked to explain why a strategy works, compare solution pathways, defend assumptions, and revise unsuccessful approaches, they practice forms of reasoning that are directly relevant to complex problem-



solving. Hiebert and Grouws (2007) similarly argued that opportunities to engage with important mathematics and struggle productively with ideas can support conceptual learning when the instructional environment provides coherence and support.

Empirical work on inquiry further supports this rationale. Furtak et al. (2012), in a meta-analysis of experimental and quasi-experimental studies of inquiry-based science teaching, found an overall positive effect and highlighted the importance of teacher guidance. Although science inquiry and mathematical inquiry are not identical, both require learners to coordinate evidence, representations, and reasoning under conditions in which the solution method is not fully specified in advance. Problem-based learning research likewise shows that complex problems can stimulate self-directed learning and integration of knowledge when instruction is appropriately scaffolded (Hmelo-Silver, 2004; Hmelo-Silver et al., 2007). These findings provide a strong theoretical basis for testing guided inquiry specifically in mathematics courses.

Despite the broader evidence base for active learning, there remains a practical need for context-specific quasi-experimental studies in higher education mathematics. Effects observed in one discipline, institution, or student population cannot automatically be generalized to another. Moreover, perception-based studies can document whether students or teachers value active methodologies, but they cannot determine whether performance changes under different instructional conditions. A pretest-posttest comparison between groups, although weaker than a randomized controlled trial, can provide useful evidence when the design is transparently reported, baseline differences are examined, statistical assumptions are checked, effect sizes and confidence intervals are presented, and causal claims are appropriately limited (Shadish et al., 2002).

The present study therefore examines mathematical problem-solving performance among undergraduate students exposed to two instructional conditions: guided inquiry-based learning and conventional lecture-based instruction. The study is guided by the following question: to what extent do students receiving guided IBL show different pretest-to-posttest changes in mathematical problem-solving performance compared with students receiving conventional instruction? Consistent with the theoretical and empirical literature, it was expected that the IBL group would exhibit larger observed gains. The objective was to evaluate the association between participation in a guided IBL instructional



condition and changes in mathematical problem-solving scores in the specific higher-education context studied, while explicitly recognizing the inferential limitations of non-random group assignment.

2. METODOLOGÍA

Research Design and Setting

A quasi-experimental pretest-posttest design with a non-equivalent comparison group was used. The original study compared two existing groups of undergraduate students enrolled in a Basic Education program at a public university in Ecuador. One group received guided inquiry-based learning, and the comparison group received conventional lecture-based instruction. Students were not individually randomized. The retained manuscript did not preserve the exact academic period, dates, or campus identifier, and no unverified details are introduced in this revision. Accordingly, the design is treated as a non-randomized comparison of instructional conditions and causal claims are deliberately limited.

Participants, Eligibility, and Group Allocation

Participants were undergraduate students enrolled in a Basic Education program and recruited through non-probability sampling from available classes. The original study used two pre-existing instructional groups. The exact analytic sample size and exact group counts could not be recovered after loss of the original participant-level database. Because approximate values are unsuitable for scientific reporting, no reconstructed counts are presented as observed data. This limitation is explicitly considered when interpreting the findings.

Baseline performance is described only from the group summaries archived: $M = 5.21$ ($SD = 1.12$) for the IBL group and $M = 5.18$ ($SD = 1.15$) for the comparison group. These nearly identical descriptive means indicate similar observed starting performance on the retained outcome summary, but they do not establish equivalence on unmeasured characteristics.

Instructional Intervention

Both groups studied the same mathematical content and were expected to achieve the same curricular learning outcomes. The instructional difference concerned the way students engaged with the content. The guided IBL condition used problem situations and structured inquiry sequences in which students were asked to identify relevant information, formulate



questions or conjectures, propose solution strategies, test or compare procedures, justify conclusions, and discuss the validity of their reasoning. The instructor supported the process through prompts, targeted questions, clarification, and feedback rather than by immediately providing complete solution procedures.

The comparison condition received conventional lecture-based instruction covering the same mathematical content. Instruction included teacher explanation, worked examples, and individual practice exercises. The retained study description indicates that the principal instructional contrast concerned the form of student engagement rather than the mathematical content.

The intervention was implemented as a short instructional sequence embedded in regular course activity. However, the exact number of weeks, instructional sessions, and minutes per session could not be recovered from verifiable records. These values are therefore not reconstructed or estimated in this report.

Mathematical Problem-Solving Assessment

Mathematical problem-solving was assessed using a structured test administered before and after the instructional period. The surviving manuscript indicates that the assessment addressed logical reasoning, problem-solving strategies, and the application of mathematical concepts. The exact final number of items and total score range were not preserved in the retained records; consequently, the present revision does not introduce reconstructed values. The surviving manuscript states that content validity was established through expert review. However, the number of experts, rating procedure, and quantitative content-validity results were not retained in the available records. These details are therefore reported as unavailable rather than reconstructed.

The surviving manuscript also states that internal consistency was evaluated using Cronbach's alpha, but the exact coefficient and the dataset on which it was calculated could not be recovered. No reliability coefficient is reported in this revision because it cannot be legitimately derived from group means and standard deviations.

Procedure

Participants completed a pretest before exposure to the differentiated instructional conditions and a posttest after the instructional period. The retained study documentation states that participation was voluntary and that informed consent, confidentiality, and



anonymity were addressed. The same conceptual assessment framework was used at both measurement occasions.

Statistical Analysis

Because the original student-level database is no longer available, a new inferential reanalysis could not be performed. The present revision therefore reports only aggregate descriptive statistics preserved in the earlier manuscript. Previously reported *t* statistics and Cohen's *d* values were not retained because they could not be independently reproduced from verifiable individual-level records and were internally inconsistent with the archived descriptive summaries. No synthetic or reconstructed participant-level dataset was used to generate the empirical results presented here.

Descriptive reporting focuses on the archived means and standard deviations at pretest and posttest, together with arithmetic differences between the retained group means. Assumption tests, degrees of freedom, exact *p* values, confidence intervals, and participant-level effect sizes are not reported because the necessary raw observations are unavailable. This decision prioritizes reproducibility and prevents unsupported inferential claims.

Ethical Considerations

Participation was voluntary, and confidentiality and anonymity were protected according to the retained study documentation. The available records also state that informed consent was obtained before participation. However, the specific institutional ethics approval or authorization identifier, date, and exact consent format could not be recovered from the surviving files. Accordingly, no unverified committee name, code, or date is reported.

3. RESULTADOS

Archived Descriptive Baseline

The original participant-level file and exact analytic sample counts were not recoverable. For that reason, this revision does not present reconstructed participant numbers or participant-flow estimates. The results below are limited to the aggregate pretest and posttest summaries preserved in the original manuscript.

At pretest, the retained summaries were very similar: $M = 5.21$ ($SD = 1.12$) in the IBL group and $M = 5.18$ ($SD = 1.15$) in the comparison group, an aggregate mean difference of 0.03 points. Because participant-level data are unavailable, no inferential baseline test is reported.



Descriptive Pretest and Posttest Performance

The summaries archived indicate improvement in both groups. The IBL group increased from $M = 5.21$ to $M = 8.34$, an arithmetic mean gain of 3.13 points. The comparison group increased from $M = 5.18$ to $M = 6.02$, a mean gain of 0.84 points. At posttest, the difference between group means was 2.32 points in favor of the IBL condition. These are descriptive contrasts only and should not be interpreted as statistically verified treatment effects.

Table 1.

Archived descriptive statistics for mathematical problem-solving scores.

Group	Measurement	Mean	SD	Mean change
Inquiry-based learning	Pretest	5.21	1.12	
Inquiry-based learning	Posttest	8.34	0.98	3.13
Comparison	Pretest	5.18	1.15	
Comparison	Posttest	6.02	1.20	0.84

Note. Exact group sample sizes could not be recovered from the surviving records; therefore, the table reports only verifiable aggregate means, standard deviations, and arithmetic mean changes.

Interpretation of the Archived Descriptive Pattern

The retained descriptive pattern shows a larger mean increase in the IBL condition. However, without participant-level scores, exact group sizes, assumption checks, and a reproducible inferential model, statistical significance and the precision of the between-group difference cannot be established. Accordingly, this revision does not report Shapiro-Wilk or Levene tests, t statistics, degrees of freedom, p values, confidence intervals, or standardized effect sizes.

Statistical Reporting Limitation

The earlier draft contained inferential statistics for within-group and between-group comparisons. Those values are excluded from this revision because they cannot be independently reproduced from the data that remain available. The results are therefore confined to the verifiable aggregate means and standard deviations presented in Table 1.

4. DISCUSIÓN



The purpose of this study was to examine whether undergraduate students who participated in a guided inquiry-based learning condition displayed a different descriptive pattern of change in mathematical problem-solving performance from students receiving conventional lecture-based instruction. The archived group summaries show improvement in both conditions, but the increase was larger in the IBL group (3.13 points) than in the comparison group (0.84 points), with a 2.32-point difference between archived posttest means. Because the original individual-level database is unavailable, these contrasts are treated as descriptive rather than inferential evidence.

This descriptive pattern is consistent with the broader literature on active learning. Freeman et al. (2014) found that active learning improved examination performance across STEM disciplines and reduced failure relative to traditional lecturing. The present study addresses a more specific outcome—mathematical problem-solving—and a more specific active-learning model. The likely value of IBL in this context lies not simply in increasing classroom activity, but in changing the cognitive work expected of students. Rather than receiving a complete procedure and reproducing it, students are required to interpret problems, generate or compare strategies, provide reasons, examine evidence, and reflect on the adequacy of solutions.

This mechanism is closely aligned with theories of mathematical problem-solving. Schoenfeld (1985) emphasized that expert performance depends on monitoring and strategic control as well as on mathematical knowledge. Guided inquiry can make these processes visible and practicable. Open-ended questioning requires students to identify what is relevant; hypothesis or conjecture formation requires them to anticipate mathematical relationships; collaborative reasoning requires articulation and evaluation of alternatives; and reflective discussion requires them to revisit both successful and unsuccessful approaches. These processes may help explain why an inquiry-oriented environment could produce stronger performance on tasks that demand transfer and reasoning rather than simple procedural recall.

The archived pattern is also compatible with the emphasis on guidance in inquiry research. Lazonder and Harmsen (2016) showed that learning outcomes in inquiry settings are generally strengthened by guidance. Likewise, Alfieri et al. (2011) distinguished between minimally guided discovery and enhanced forms of discovery that include



feedback, scaffolding, worked examples, or elicited explanations. The IBL approach described in the present study was intended to be guided rather than minimally supervised. This distinction matters because students in higher education are not automatically expert problem solvers. When tasks contain multiple interacting elements, unguided search can consume cognitive resources without producing durable understanding. Carefully designed prompts and instructor feedback can focus student effort on mathematically productive reasoning.

The descriptive findings can also be considered in relation to Furtak et al. (2012), whose meta-analysis reported positive effects for inquiry-based teaching and highlighted stronger outcomes in teacher-guided forms of inquiry. Although that meta-analysis focused primarily on science education, the underlying instructional principle is relevant: inquiry is most effective when learners engage in authentic reasoning processes while receiving sufficient structure to connect those processes to disciplinary knowledge. In mathematics, guidance may be especially important when students must coordinate symbolic representations, conceptual relationships, and multi-step reasoning.

At the same time, the observed improvement in the comparison group should not be dismissed. Conventional instruction can support learning, especially when explanations, examples, and practice are well designed. The relevant question is therefore not whether lecture-based teaching is inherently ineffective, but whether guided inquiry may provide additional support for outcomes that require flexible problem-solving. In the summaries archived, the IBL group displayed the larger mean gain, but the absence of reproducible inferential statistics prevents a definitive claim of statistical superiority. From a practical perspective, inquiry episodes can be embedded within a broader instructional sequence in which explanation, modeling, practice, inquiry, and feedback are coordinated.

The raw descriptive differences should be interpreted cautiously. The IBL group's archived mean gain was 3.13 points, compared with 0.84 points in the comparison group, and the posttest means differed by 2.32 points. These values may be educationally relevant, but the exact score range, analytic sample size, confidence intervals, and raw-data-based standardized effect could not be recovered. Consequently, this revision does not assign a Cohen's *d* value or characterize the observed difference as statistically significant.



Studying has several implications for higher education. First, mathematics instruction can be designed to make reasoning an explicit object of teaching. Students can be asked not only for answers but for assumptions, representations, alternative pathways, and explanations. Second, inquiry tasks should be sequenced and scaffolded. Guidance can be gradually reduced as students gain familiarity with the problem-solving process. Third, collaborative inquiry can be used strategically to expose students to different solution paths, but participation structures should ensure that all learners engage cognitively rather than relying on a small number of peers. Fourth, assessment should align with the intended outcome. If the instructional objective is flexible problem-solving, tests should include problems that require interpretation and justification rather than only routine exercises.

The results may be particularly relevant to teacher education. Future teachers require opportunities to experience mathematics as a discipline of reasoning and inquiry, because their own instructional choices will shape the mathematical experiences of school students. Exposure to guided IBL may support not only their immediate performance but also their understanding of how questions, conjectures, representations, discussion, and feedback can be orchestrated pedagogically. This broader professional implication should nevertheless be examined directly in future research rather than inferred from problem-solving scores alone. Several limitations constrain the interpretation of the present study. The first is non-probability sampling, which limits population generalization. The participants represent students accessible within a particular institutional and curricular context, and the findings should not be generalized automatically to all higher-education students or to other national settings. Replication across institutions, degree programs, and levels of mathematical preparation is needed.

A second limitation is the absence of individual random assignments. When intact or administratively formed groups are compared, observed post-intervention differences may reflect the instructional condition, but they may also be influenced by pre-existing group characteristics, instructor effects, scheduling, peer composition, prior experiences, or other unmeasured factors. Similar pretest means reduce one concern but do not eliminate selection bias. For this reason, the revised manuscript deliberately avoids phrases such as “identification of causal relationships” and “strong empirical evidence” when those phrases imply randomized causal identification. Future studies should use random



assignment when feasible or employ stronger quasi-experimental controls, such as matched groups, multiple baseline covariates, or repeated cohorts.

A third limitation concerns incomplete recovery of intervention and measurement documentation. The exact duration and number of sessions, the definitive item count and score range of the problem-solving test, the number of expert validators, and the original reliability coefficient could not be verified from the surviving files. This restricts replication and prevents a full assessment of measurement quality. Future studies should archive protocols, instrument versions, scoring rubrics, fidelity records, and reliability outputs in redundant institutional or cloud repositories.

A fifth limitation is the possibility of teacher and implementation effects. If the same instructor taught both groups, contamination between conditions is possible; if different instructors taught the groups, instructor characteristics become a potential confound. Fidelity evidence, such as lesson plans or observation records, can help clarify whether the intended instructional contrast was implemented. Finally, the use of the same or highly similar test at pretest and posttest may introduce practice effects. Future research could use parallel forms or include transfer tasks to assess whether learning extends beyond familiarity with specific item formats.

The most important limitation is the loss of the original individual-level database. This prevents exact recalculation of participant flow, assumptions, confidence intervals, p values, and standardized effect sizes. The present revision therefore deliberately restricts the Results section to aggregate values that can be traced to the surviving manuscript and excludes unreproducible inferential statistics. This approach reduces the strength of the conclusions but preserves scientific transparency and avoids presenting synthetic or reconstructed observations as original empirical data.

5. CONCLUSIÓN

This quasi-experimental study compared archived pretest and posttest summaries from guided inquiry-based learning and conventional lecture-based instruction in undergraduate mathematics education. The retained descriptive results show a larger mean increase in the IBL group (3.13 points) than in the comparison group (0.84 points), together with a 2.32-



point difference between archived posttest means. These values indicate a favorable descriptive pattern for guided IBL in the instructional context examined.

The findings should nevertheless be interpreted conservatively. The original participant-level database and exact analytic sample counts were not recoverable, so inferential statistics, confidence intervals, assumption checks, and standardized effect sizes could not be independently reproduced. The study therefore does not claim definitive causal superiority of IBL. Instead, it provides context-specific descriptive evidence consistent with the broader literature on guided inquiry and active mathematical reasoning.

For practice, the study suggests that university mathematics courses may benefit from integrating carefully scaffolded inquiry tasks with explicit instruction and feedback. For research, future studies should use prospectively documented sample flows, preserved individual-level datasets, validated measurement instruments, stronger allocation procedures, longer follow-up periods, and transparent reporting of implementation fidelity. These steps are necessary to determine the durability, generalizability, and statistical precision of inquiry-based approaches for mathematical problem-solving in higher education.

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CONFLICT OF INTEREST

None.

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