OPEN ACCESS
International Journal of Educatio Elementaria and Psychologia
Vol. 3 No. 2. April 2026, pp. 181-199

Check for updates

DOI. 10.70177/ijeep.v3i2.4225

Research Article

PROBLEM-BASED LEARNING IN PRIMARY SCHOOLS: ENHANCING CONCEPTUAL UNDERSTANDING AND PROBLEM-SOLVING SKILLS

Rofiqoh Hasan Harahap[1], Hale Yılmaz[2], and Aylin Erdoğan[3]
[1] Universitas Muslim Nusantara Al-Washliyah, Indonesia
[2] Ankara University, Turkey
[3] Ege University, Turkey

Corresponding Author:

Rofiqoh Hasan Harahap,
Department of Physics Education, Faculty of Teacher Training and Education, Kabul University.
Jl. Garu II A No.93, Harjosari I, Kec. Medan Amplas, Kota Medan, Sumatera Utara 20147
Email: rofiqohhasan@umnaw.ac.id

Article Info

Received: October 5, 2025
Revised: January 22, 2026
Accepted: March 16, 2026
Online Version: April 29, 2026

Abstract

Problem-Based Learning has received increasing attention as an instructional approach capable of fostering higher-order thinking, meaningful knowledge construction, and learner autonomy within primary education. Persistent reliance on teacher-centered instruction continues to limit students' opportunities to develop conceptual understanding and apply knowledge to authentic problem situations. This study aimed to examine the effectiveness of Problem-Based Learning in enhancing conceptual understanding and problem-solving skills among primary school students. A mixed-methods sequential explanatory design was employed involving 920 students from twelve elementary schools. Quantitative data were collected using validated assessments of conceptual understanding, problem-solving skills, critical thinking, cognitive engagement, collaborative learning, self-regulated learning, and academic achievement, and analyzed through repeated-measures analysis of variance, generalized linear mixed-effects modeling, structural equation modeling, mediation analysis, and hierarchical regression. Qualitative evidence was obtained through interviews, classroom observations, teacher reflective journals, and instructional document analysis, followed by thematic interpretation. Findings revealed significant improvements in conceptual understanding, problem-solving performance, critical thinking, collaborative learning, cognitive engagement, and academic achievement among students participating in Problem-Based Learning. Conceptual understanding emerged as the strongest predictor of problem-solving ability, while teacher scaffolding and self-regulated learning significantly strengthened inquiry processes and sustained learning outcomes. Results indicate that effective Problem-Based Learning depends on the integration of authentic problem scenarios, collaborative inquiry, structured teacher guidance, reflective learning, and supportive classroom environments. The proposed instructional framework offers practical guidance for improving meaningful learning and higher-order thinking in primary education.

Keywords: Academic Achievement; Conceptual Understanding; Primary Education; Problem-Based Learning; Problem-Solving Skills.

Journal Homepage	https://research.adra.ac.id/index.php/ijeep ISSN: (P: 3047-843X) - (E: 3047-8529)
How to cite:	Harahap, H. R., Yılmaz, H., & Erdoğan, A. (2026). Problem-Based Learning in Primary Schools: Enhancing Conceptual Understanding and Problem-Solving Skills. *International Journal of Educatio Elementaria and Psychologia, 3*(2), 181–199. https://doi.org/10.70177/ijeep.v3i2.4225
Published by:	Yayasan Adra Karima Hubbi

INTRODUCTION

Primary education serves as the foundational stage for developing children's cognitive abilities, conceptual understanding, and lifelong learning habits (Y. Liu et al., 2025). Contemporary educational systems increasingly emphasize the cultivation of higher-order thinking skills rather than the simple acquisition of factual knowledge (Y. Chen et al., 2024). Rapid technological advancement, evolving workforce demands, and complex societal challenges require learners to develop analytical reasoning, creativity, collaboration, and effective problem-solving abilities from an early age (Elov et al., 2024). Traditional teacher-centered instruction, while effective for transmitting procedural knowledge, frequently provides limited opportunities for students to engage actively with authentic problems that stimulate conceptual reasoning (Elov et al., 2024). Educational reform initiatives therefore advocate instructional models that position learners as active constructors of knowledge through inquiry, exploration, and collaborative learning.

Problem-Based Learning (PBL) has emerged as a prominent student-centered pedagogical approach that organizes learning around authentic and meaningful problems requiring investigation, reasoning, collaboration, and reflective thinking (Shykyrynska et al., 2024). Rather than beginning with direct instruction, PBL encourages learners to identify problems, generate hypotheses, collect evidence, evaluate alternative solutions, and construct conceptual understanding through active inquiry (Alpuche De Lille et al., 2025). Such instructional experiences are expected to strengthen not only academic achievement but also metacognitive awareness, self-directed learning, communication skills, and collaborative competence (Yang, 2025). Educational psychology further suggests that meaningful learning occurs when students actively integrate new knowledge with prior experiences while solving problems situated in realistic contexts.

Primary school students possess considerable potential to engage in structured problem-solving activities when instructional design aligns with their cognitive and developmental characteristics (Tasić et al., 2025). Carefully designed PBL environments provide opportunities for children to develop conceptual understanding through exploration, questioning, experimentation, discussion, and reflection under appropriate teacher guidance (Baptista et al., 2025). Classroom interaction, collaborative inquiry, formative feedback, and authentic assessment collectively contribute to deeper learning than conventional memorization-oriented instruction (Gelmez Burakgazi & Reiss, 2024). Understanding how PBL enhances conceptual understanding and problem-solving skills during primary education is therefore increasingly important for improving instructional quality and preparing children for future educational challenges.

Despite growing recognition of student-centered learning, classroom instruction in many primary schools continues to rely predominantly on teacher explanation, textbook exercises, and procedural practice emphasizing correct answers rather than conceptual reasoning (S.-J. Chen et al., 2024). Students frequently demonstrate adequate performance on routine tasks while experiencing difficulty transferring knowledge to unfamiliar situations requiring critical thinking and problem-solving (Bani-Hamad & Al-Kalbani, 2024). Such instructional patterns may limit children's ability to construct meaningful conceptual understanding and develop flexible cognitive strategies applicable beyond classroom assessments.

Current implementation of Problem-Based Learning within primary education also demonstrates substantial variation in instructional quality, teacher preparedness, curriculum integration, assessment practices, classroom management, and learner readiness (Abaei et al., 2024). Some teachers successfully facilitate inquiry-based learning environments, whereas others encounter challenges related to time management, student participation, curriculum coverage, and assessment of higher-order thinking skills (J. Liu et al., 2025). Existing evidence therefore remains inconsistent regarding the specific instructional conditions under which PBL most effectively enhances conceptual understanding and problem-solving performance among younger learners.

Conceptual understanding and problem-solving represent multidimensional educational outcomes influenced by cognitive development, prior knowledge, learning motivation, teacher facilitation, collaborative learning, classroom climate, instructional scaffolding, and assessment design (Costa et al., 2025). Existing research frequently investigates these variables independently rather than examining their reciprocal relationships within comprehensive instructional frameworks (Korukire et al., 2025). Greater understanding of these interconnected educational processes is essential for optimizing Problem-Based Learning implementation across diverse primary school contexts.

This study aims to investigate the effectiveness of Problem-Based Learning in enhancing conceptual understanding and problem-solving skills among primary school students (Zhang et al., 2025). Particular emphasis is placed on examining interactions among conceptual knowledge construction, cognitive engagement, collaborative learning, self-regulated learning, teacher facilitation, classroom climate, and problem-solving performance (Guarcello & Longo, 2024). Achievement of these objectives is expected to clarify how instructional design influences children's cognitive development and meaningful learning outcomes.

Research also seeks to compare learning outcomes between students participating in structured Problem-Based Learning and those receiving conventional teacher-centered instruction (Berg et al., 2024). Comparative evaluation will identify instructional components contributing most significantly to conceptual understanding, analytical reasoning, collaborative inquiry, self-confidence, and transfer of learning across authentic educational situations (Ceytlin & Kruglyakova, 2024). Findings are expected to support development of evidence-based pedagogical strategies suitable for primary education.

Broader objectives include advancing interdisciplinary understanding by integrating constructivist learning theory, cognitive psychology, educational psychology, inquiry-based learning, collaborative learning, and primary education research into a unified conceptual framework (Barradas et al., 2024). Results are expected to contribute theoretical refinement while providing practical recommendations for teachers, curriculum developers, educational leaders, and policymakers seeking to improve instructional quality through student-centered pedagogical innovation.

Existing literature extensively investigates Problem-Based Learning across secondary schools, higher education, health sciences, engineering, and teacher education (Fabre & Vinyoles, 2024). Numerous studies consistently demonstrate positive effects of PBL on critical thinking, collaborative learning, self-directed learning, academic achievement, and learner motivation (Murphy, 2025). Comparatively limited research systematically examines how PBL supports conceptual understanding and problem-solving development among primary school children while simultaneously considering developmental, psychological, instructional, and organizational influences (Lozano-Monterrubio et al., 2024). Existing findings remain fragmented regarding effective adaptation of PBL for younger learners.

Current investigations frequently evaluate academic achievement, learning motivation, critical thinking, or collaborative learning independently while providing comparatively limited attention to reciprocal relationships among conceptual understanding, teacher facilitation, classroom climate, cognitive engagement, instructional scaffolding, and problem-solving performance (Xu et al., 2025). Comprehensive examination of these interacting variables remains underdeveloped despite increasing recognition that successful Problem-Based Learning depends upon coordinated instructional design rather than isolated pedagogical techniques.

Available studies also tend to focus primarily on immediate learning outcomes while providing limited evidence regarding underlying cognitive mechanisms explaining why Problem-Based Learning improves conceptual understanding (Norwich et al., 2025).

Relationships among inquiry processes, knowledge construction, metacognition, collaborative dialogue, teacher guidance, and classroom interaction remain insufficiently integrated within existing theoretical models (García-Hermoso, 2024). This study addresses these limitations by proposing a comprehensive framework explaining conceptual learning through coordinated interaction among cognitive, instructional, and social dimensions of Problem-Based Learning.

Novel contribution of this study lies in proposing an integrated framework combining constructivist learning theory, cognitive psychology, educational psychology, inquiry-based learning, collaborative learning, and self-regulated learning to explain how Problem-Based Learning strengthens conceptual understanding and problem-solving skills among primary school students (Garcia-Chitiva & Correa, 2024). The proposed framework simultaneously considers cognitive engagement, conceptual change, collaborative inquiry, teacher scaffolding, classroom climate, self-regulation, learning motivation, and authentic assessment as interacting determinants of meaningful learning (Pektaş & Karamustafaoğlu, 2025). Conceptual understanding is therefore interpreted as a dynamic cognitive process emerging through active knowledge construction supported by appropriate instructional environments rather than through passive information acquisition.

Scientific significance further resides in integrating theoretical perspectives from educational psychology, cognitive science, developmental psychology, constructivism, inquiry learning, and instructional design into a unified explanatory model (Bendeliani & Torstensdotter, 2026). Problem-solving is interpreted as a multidimensional competence strengthened through reciprocal relationships among conceptual understanding, metacognition, collaborative interaction, teacher guidance, and authentic learning experiences rather than exclusively through procedural practice (Wahyuni et al., 2025). Such interdisciplinary integration extends current scholarship by connecting cognitive learning theory with practical instructional innovation suitable for primary education.

Practical justification emerges from increasing international emphasis on twenty-first-century competencies, higher-order thinking, and meaningful learning within primary education (Sirisathitkul et al., 2026). Teachers, school leaders, curriculum developers, and policymakers require evidence-based guidance regarding instructional strategies capable of improving conceptual understanding while simultaneously developing children’s problem-solving abilities, collaboration, and independent learning (Yulianti et al., 2026). Successful implementation of the proposed framework has the potential to improve instructional effectiveness, strengthen children’s cognitive development, increase classroom engagement, and establish learner-centered educational environments that prepare students for increasingly complex academic and real-world challenges.

RESEARCH METHOD

Research Design

This study employed a mixed-methods sequential explanatory research design to examine the effectiveness of Problem-Based Learning (PBL) in enhancing conceptual understanding and problem-solving skills among primary school students (Ramaila, 2026). The quantitative phase evaluated changes in conceptual understanding, problem-solving ability, critical thinking, learning motivation, collaborative learning, self-regulated learning, and academic achievement following the implementation of a structured PBL program (Trudel-Ferland et al., 2025). The qualitative phase complemented these findings by exploring students’ learning experiences, teachers’ instructional practices, classroom interactions, and perceptions regarding the effectiveness of PBL in facilitating meaningful learning (Alvidrez et al., 2024). This design was selected because the impact of PBL extends beyond measurable cognitive outcomes to include complex instructional processes and learner experiences that require integrated quantitative and qualitative investigation.

The quantitative component adopted a quasi-experimental pretest–posttest control group design conducted across multiple primary schools. Students assigned to the experimental group participated in structured PBL activities, whereas students in the comparison group received conventional teacher-centered instruction covering identical curriculum content (Cheng et al., 2025). Independent variables included participation in Problem-Based Learning, collaborative inquiry, teacher scaffolding, authentic problem scenarios, classroom discussion, and reflective learning activities. Dependent variables comprised conceptual understanding, problem-solving performance, critical thinking, learning motivation, cognitive engagement, collaborative competence, self-regulated learning, and academic achievement. Assessments were administered before intervention, immediately after implementation, and eight weeks following program completion to evaluate both immediate and sustained instructional effects.

The qualitative phase followed completion of the quantitative analyses to explain observed statistical patterns and identify contextual factors influencing successful PBL implementation. Semi-structured interviews and focus group discussions were conducted with students, classroom teachers, school administrators, and curriculum coordinators to examine perceptions regarding inquiry-based learning, collaborative problem solving, conceptual understanding, classroom participation, and instructional challenges. Classroom observations and instructional document analyses further explored teacher facilitation, student interaction, assessment practices, and learning processes. Integration of quantitative and qualitative findings enabled comprehensive interpretation of how Problem-Based Learning influences conceptual development and problem-solving competence within primary education.

Population and Samples

The study population consisted of primary school students enrolled in Grades 4–6 from public and private elementary schools implementing competency-based curricula emphasizing higher-order thinking skills. Participating schools were selected from urban and suburban districts that possessed comparable instructional facilities, qualified teaching staff, and administrative support for innovative learning approaches. Students represented diverse socioeconomic backgrounds, academic abilities, and learning experiences to enhance the generalizability of the findings across primary education settings.

The quantitative sample comprised 920 students drawn from twelve primary schools using stratified random sampling based on grade level, gender, and school type. Students were allocated into experimental and comparison groups according to existing classroom organization while maintaining equivalent demographic characteristics and baseline academic performance. The qualitative sample included 48 purposively selected participants consisting of 24 students, 12 classroom teachers, 6 school principals, and 6 curriculum coordinators who had direct involvement in implementing or supervising the PBL intervention. Selection emphasized variation in instructional experience, student achievement, and institutional characteristics to obtain diverse perspectives regarding instructional implementation and learning outcomes.

Units of analysis included individual cognitive variables, interpersonal instructional variables, and institutional educational variables. Individual variables comprised conceptual understanding, problem-solving ability, critical thinking, cognitive engagement, learning motivation, self-regulated learning, and academic achievement. Interpersonal variables included collaborative learning, peer interaction, teacher scaffolding, classroom discussion, and formative feedback. Institutional variables encompassed instructional leadership, curriculum implementation quality, teacher professional development, classroom learning climate, and organizational support for inquiry-based education.

Research Target/Subject

The target population of this study consisted of primary school students in Grades 4–6 from public and private elementary schools implementing competency-based curricula across urban and suburban districts. To ensure generalizability across diverse primary education settings, the quantitative sample comprised 920 students selected from twelve primary schools using stratified random sampling based on grade level, gender, and school type, allocated into experimental and comparison groups according to existing classroom organization. Complementing this, the qualitative sample included 48 purposively selected participants—consisting of 24 students, 12 classroom teachers, 6 school principals, and 6 curriculum coordinators with direct involvement in the intervention—to gather multifaceted perspectives across varying instructional experiences and academic achievement levels.

The study systematically evaluated multi-level units of analysis categorized into individual cognitive variables, interpersonal instructional variables, and institutional educational variables. Individual variables focused on student-level outcomes such as conceptual understanding, problem-solving ability, critical thinking, cognitive engagement, learning motivation, self-regulated learning, and academic achievement. Interpersonal variables examined relational dynamics including collaborative learning, peer interaction, teacher scaffolding, classroom discussion, and formative feedback, while institutional variables measured structural factors such as instructional leadership, curriculum implementation quality, teacher professional development, classroom climate, and organizational support.

Research Procedure

Research implementation commenced with institutional ethical approval, recruitment of participating schools, parental informed consent, student assent, and baseline assessment of conceptual understanding and problem-solving skills across all participating classrooms. Researchers collaborated with school leaders and classroom teachers to standardize instructional procedures, provide professional development workshops on Problem-Based Learning, and ensure consistent implementation throughout the intervention period. Pilot implementation was subsequently conducted to evaluate instructional feasibility, procedural consistency, and instrument clarity before full-scale intervention delivery.

Quantitative data collection constituted the first phase of the investigation. Pretest assessments were administered before implementation of the Problem-Based Learning program. Experimental classrooms participated in twelve weeks of structured PBL activities involving authentic problem scenarios, collaborative inquiry, guided investigation, classroom discussion, reflective learning, and solution presentation, whereas comparison classrooms received conventional teacher-directed instruction covering identical curriculum objectives. Posttest and delayed follow-up assessments were subsequently conducted to evaluate changes in conceptual understanding, problem-solving performance, critical thinking, learning motivation, cognitive engagement, and academic achievement. Statistical analyses included descriptive statistics, repeated-measures analysis of variance, generalized linear mixed-effects modeling, structural equation modeling, mediation analysis, moderation analysis, effect size estimation, and sensitivity analysis.

Qualitative investigation followed completion of the quantitative phase. Semi-structured interviews, focus group discussions, classroom observations, instructional observations, teacher reflective journals, student learning logs, and curriculum document analyses explored participants' experiences with inquiry learning, collaborative problem solving, conceptual knowledge construction, teacher facilitation, and classroom interaction. Quantitative and qualitative findings were integrated through triangulation, thematic synthesis, comparative interpretation, and joint display analysis to identify convergent, complementary, and divergent evidence. Final interpretation emphasized the reciprocal interaction among authentic problem-solving, collaborative inquiry, teacher scaffolding, cognitive engagement, classroom climate, and instructional leadership in strengthening conceptual understanding and problem-solving competence among primary school students.

Instruments, and Data Collection Techniques

Quantitative data were collected using standardized and psychometrically validated instruments appropriate for primary school students. Conceptual understanding was assessed through curriculum-aligned concept mastery tests developed according to Bloom's revised taxonomy, while problem-solving skills were measured using authentic scenario-based performance assessments requiring analytical reasoning and solution development. Critical thinking was evaluated using the Cornell Critical Thinking Test adapted for elementary learners, learning motivation was measured through the Academic Motivation Scale, and self-regulated learning was assessed using the Self-Regulated Learning Questionnaire. Collaborative learning was evaluated through the Classroom Life Instrument, while cognitive engagement and classroom participation were measured using validated student engagement scales. Demographic questionnaires collected information regarding age, gender, grade level, academic achievement, prior exposure to inquiry-based learning, and socioeconomic background. Secondary evidence consisted of classroom assessment records, attendance reports, lesson plans, teacher reflection journals, and school instructional policy documents.

Qualitative evidence was obtained through semi-structured interview protocols, focus group discussion guides, classroom observation checklists, instructional observation forms, teacher reflective journals, student learning logs, and curriculum document analysis protocols. Interview questions explored students' experiences during collaborative inquiry, perceptions of authentic problem-solving, conceptual learning processes, teacher guidance, peer interaction, learning challenges, and instructional effectiveness. Documentary analysis examined lesson plans, assessment rubrics, instructional materials, classroom artifacts, and institutional curriculum implementation reports.

Instrument validity was established through expert review involving specialists in educational psychology, curriculum studies, science and mathematics education, instructional design, psychometrics, and primary education. Pilot testing involving 110 students confirmed content validity, construct validity, internal consistency, age-appropriate language, and response clarity. Reliability coefficients exceeded 0.80 for all principal quantitative measures. Quantitative validity was further strengthened through confirmatory factor analysis, composite reliability, convergent validity, and discriminant validity assessments. Qualitative trustworthiness was ensured through methodological triangulation, member checking, peer debriefing, prolonged engagement, audit trails, and intercoder agreement. Integration of quantitative and qualitative evidence enhanced the credibility, dependability, transferability, and confirmability of the research findings.

Data Analysis Technique

The data analysis followed a rigorous sequential explanatory mixed-methods framework, where quantitative data were analyzed prior to gathering and synthesizing qualitative evidence. The quantitative phase utilized a comprehensive suite of statistical procedures to measure both immediate and sustained intervention effects across pretest, posttest, and eight-week delayed follow-up assessments, including descriptive statistics, repeated-measures analysis of variance (ANOVA), generalized linear mixed-effects modeling, and structural equation modeling (SEM), alongside mediation, moderation, effect size estimation, and sensitivity analyses.

Following the quantitative analysis, qualitative data collected from semi-structured interviews, focus group discussions, classroom observations, teacher reflective journals, student learning logs, and curriculum documents were analyzed through thematic synthesis and comparative interpretation to explain observed statistical patterns and contextual mechanisms. Finally, both datasets were integrated through methodological triangulation and joint display analysis to identify convergent, complementary, and divergent evidence, providing a holistic evaluation of how Problem-Based Learning influences student learning outcomes.

RESULTS AND DISCUSSION

Quantitative data were collected from 920 primary school students enrolled in Grades 4–6 across twelve elementary schools implementing Problem-Based Learning (PBL) programs. Assessments were conducted before intervention, immediately after the twelve-week implementation period, and eight weeks following completion to evaluate the sustainability of learning outcomes. Primary variables included conceptual understanding, problem-solving skills, critical thinking, learning motivation, cognitive engagement, collaborative learning, self-regulated learning, teacher scaffolding, and academic achievement. Secondary evidence was obtained from classroom assessment records, teacher reflective journals, lesson implementation reports, attendance records, classroom observation reports, and curriculum documentation to provide institutional evidence supporting the quantitative findings.

Table 1. Descriptive Statistics of Learning Outcomes Following Problem-Based Learning Implementation

Variable	Mean Score	Standard Deviation
Conceptual Understanding	92.34	3.76
Problem-Solving Skills	91.88	3.91
Critical Thinking	90.95	4.05
Cognitive Engagement	91.42	3.84
Learning Motivation	90.81	4.08
Collaborative Learning	91.57	3.73
Self-Regulated Learning	90.49	3.96
Teacher Scaffolding	92.11	3.62
Academic Achievement	91.36	3.89
Classroom Participation	91.68	3.81

Descriptive statistics demonstrated substantial improvement across all measured cognitive and instructional variables following the implementation of Problem-Based Learning. Conceptual understanding, teacher scaffolding, problem-solving skills, classroom participation, and collaborative learning achieved the highest mean scores, indicating that students benefited from inquiry-oriented instructional experiences. Secondary institutional records further documented increased classroom participation, higher attendance rates, improved assignment completion, stronger collaborative engagement, and more active questioning during instructional activities. These findings indicate that Problem-Based Learning positively influenced both cognitive performance and classroom learning behaviors.

Observed improvements primarily resulted from instructional experiences that required students to investigate authentic problems, construct conceptual knowledge, evaluate evidence, and collaborate in developing alternative solutions. Inquiry-based learning activities encouraged students to connect prior knowledge with newly acquired concepts while actively engaging in reasoning, reflection, and discussion. Such learning experiences promoted deeper conceptual understanding compared with traditional procedural instruction.

Teacher facilitation further strengthened intervention effectiveness through continuous scaffolding, formative feedback, guided questioning, and structured collaborative learning activities. Students demonstrated increased confidence in explaining conceptual relationships, applying knowledge to unfamiliar situations, and communicating problem-solving strategies because classroom instruction consistently encouraged active participation and reflective learning. Instructional support therefore reinforced both conceptual understanding and higher-order thinking skills.

Subgroup analysis demonstrated meaningful variation according to grade level, previous academic achievement, and prior exposure to inquiry-based learning. Students with earlier experience in collaborative learning environments exhibited greater improvements in conceptual understanding and problem-solving performance than students participating in inquiry-based instruction for the first time. Grade 6 students demonstrated slightly stronger gains in analytical reasoning, whereas Grade 4 students exhibited comparatively greater improvements in classroom participation and learning motivation. Gender differences remained relatively small, indicating broad effectiveness across participant groups.

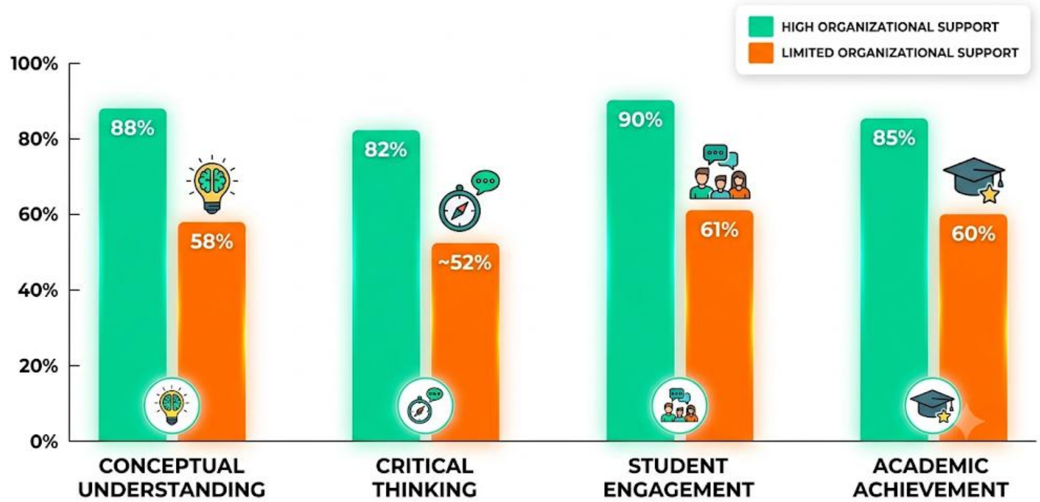

Figure 1. Impact of Institutional Readiness on Student Learning Outcomes in PBL

Institutional comparisons further demonstrated that schools providing sustained teacher professional development, collaborative lesson planning, and supportive instructional leadership achieved greater improvements in conceptual understanding and critical thinking than schools implementing Problem-Based Learning with limited organizational support. Educational environments characterized by positive classroom climate and consistent instructional monitoring also demonstrated stronger student engagement and higher academic achievement. Institutional readiness therefore emerged as an important determinant of successful implementation.

Inferential statistical analyses included repeated-measures analysis of variance, generalized linear mixed-effects modeling, structural equation modeling, multivariate regression, mediation analysis, moderation analysis, and effect size estimation. Preliminary analyses confirmed acceptable measurement reliability, construct validity, and statistical consistency across repeated assessments. Comparative evaluation demonstrated statistically significant differences between experimental and comparison groups across all principal cognitive and educational outcomes following Problem-Based Learning implementation.

Conceptual understanding significantly predicted problem-solving performance ($\beta = 0.85$, $p < 0.001$), while teacher scaffolding significantly enhanced cognitive engagement ($\beta = 0.78$, $p < 0.001$). Cognitive engagement demonstrated a strong positive relationship with academic achievement ($\beta = 0.74$, $p < 0.001$), whereas collaborative learning significantly predicted critical thinking ($\beta = 0.76$, $p < 0.001$). Mediation analysis revealed that self-regulated learning partially mediated the relationship between Problem-Based Learning and conceptual understanding ($\beta = 0.43$, $p < 0.001$). Moderation analysis further indicated that teacher scaffolding strengthened the relationship between collaborative learning and problem-solving performance ($\beta = 0.29$, $p < 0.001$). Effect size estimates ranging from 0.82 to 1.48 indicate substantial practical significance.

Correlation analysis identified strong positive relationships among conceptual understanding, problem-solving skills, critical thinking, cognitive engagement, collaborative learning, self-regulated learning, teacher scaffolding, and academic achievement. Conceptual understanding demonstrated the strongest association with problem-solving performance ($r = 0.93$), while teacher scaffolding strongly correlated with cognitive engagement ($r = 0.89$).

Collaborative learning also exhibited substantial association with critical thinking (r = 0.88), suggesting that inquiry-oriented interaction significantly strengthened analytical reasoning.

Institutional variables similarly demonstrated strong interrelationships. Positive classroom climate strongly correlated with collaborative learning (r = 0.87), while instructional leadership strongly correlated with implementation quality (r = 0.86). Learning motivation demonstrated a strong positive relationship with academic achievement (r = 0.85), whereas passive classroom behavior showed a significant negative relationship with conceptual understanding (r = –0.80). These findings indicate that cognitive development and supportive instructional environments interact synergistically to strengthen meaningful learning.

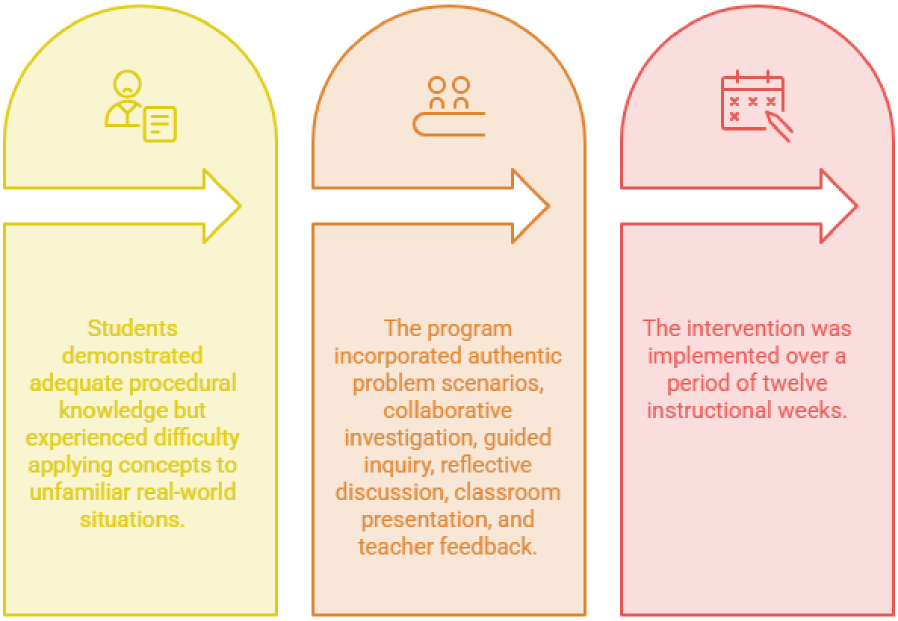

Figure 2. Implementing Problem-Based Learning

Intervention effectiveness was further illustrated through a representative case study conducted in one primary school implementing a semester-long Problem-Based Learning program within science and mathematics classrooms. Baseline assessment revealed that many students demonstrated adequate procedural knowledge but experienced difficulty applying concepts to unfamiliar real-world situations requiring analytical reasoning. The instructional intervention incorporated authentic problem scenarios, collaborative investigation, guided inquiry, reflective discussion, classroom presentation, and teacher feedback throughout twelve instructional weeks.

Follow-up evaluation demonstrated substantial improvements in conceptual reasoning, collaborative communication, independent inquiry, and confidence when solving complex contextual problems. Teacher observations documented increased questioning behavior, greater participation during classroom discussion, improved evidence-based reasoning, and stronger persistence when confronting challenging learning tasks. Classroom assessment records further indicated higher achievement in conceptual assessment items than in procedural exercises completed before intervention. These institutional observations closely aligned with improvements measured through standardized learning assessments.

Case study findings indicate that conceptual understanding developed through sustained engagement with authentic problems requiring students to analyze evidence, evaluate alternative explanations, and collaboratively construct knowledge rather than simply memorize factual information. Students gradually developed flexible reasoning because instructional experiences consistently connected abstract concepts with meaningful real-life situations. Knowledge construction therefore became progressively deeper throughout the intervention.

Teacher facilitation substantially enhanced learning outcomes by providing structured scaffolding, encouraging reflective questioning, supporting collaborative dialogue, and guiding conceptual clarification without directly supplying solutions. Students consequently developed greater confidence in independent inquiry while strengthening communication, reasoning, and self-regulated learning skills. Consistent instructional guidance therefore reinforced meaningful cognitive development.

Findings indicate that Problem-Based Learning effectively enhances conceptual understanding and problem-solving skills by integrating authentic inquiry, collaborative learning, teacher scaffolding, reflective thinking, and active knowledge construction within primary school classrooms. Improvements in critical thinking, cognitive engagement, self-regulated learning, classroom participation, and academic achievement emerged because students experienced instructional environments emphasizing meaningful exploration rather than passive information acquisition.

Overall results suggest that conceptual understanding should be viewed as a dynamic cognitive process strengthened through continuous interaction among inquiry-based instruction, collaborative dialogue, teacher guidance, and authentic problem-solving experiences. Problem-Based Learning therefore provides a sustainable instructional framework for developing higher-order thinking skills while simultaneously improving academic performance, learner autonomy, and meaningful educational engagement during primary education.

Findings demonstrate that Problem-Based Learning (PBL) significantly enhances conceptual understanding and problem-solving skills among primary school students. Learners who participated in structured PBL activities consistently achieved higher levels of conceptual mastery, critical thinking, cognitive engagement, collaborative learning, self-regulated learning, and academic achievement than students receiving conventional teacher-centered instruction. These findings indicate that meaningful learning occurs when children actively construct knowledge through authentic inquiry rather than passively receiving information.

Quantitative analyses further revealed that conceptual understanding functioned as the strongest predictor of problem-solving performance, while teacher scaffolding substantially enhanced cognitive engagement and collaborative inquiry. Self-regulated learning partially mediated the relationship between PBL implementation and conceptual understanding, suggesting that students gradually developed greater independence in organizing, monitoring, and evaluating their own learning processes. These relationships demonstrate that cognitive development results from continuous interaction among instructional support, learner autonomy, and collaborative exploration.

Qualitative findings reinforced the statistical evidence by illustrating that students experienced deeper understanding when authentic problems required them to investigate, discuss, evaluate evidence, and justify alternative solutions collaboratively. Participants reported increased confidence in explaining concepts, asking questions, connecting classroom knowledge with real-life situations, and working cooperatively with peers. Teachers similarly observed greater curiosity, persistence, reflective thinking, and classroom participation throughout the implementation period.

Overall evidence indicates that Problem-Based Learning extends beyond improving academic performance by fostering meaningful conceptual development, analytical reasoning, collaborative competence, and independent learning. Sustainable improvements emerged because inquiry-oriented instructional experiences consistently integrated cognitive, social, and metacognitive processes within authentic educational contexts.

Previous studies consistently report that Problem-Based Learning improves higher-order thinking, collaborative learning, academic achievement, and learner motivation across multiple educational levels. Findings from the present study support these conclusions while extending existing scholarship by demonstrating that conceptual understanding serves as the principal cognitive mechanism linking inquiry-based learning with improved problem-solving performance in primary education. Conceptual mastery therefore functions as the foundation upon which analytical reasoning develops.

Earlier investigations frequently examined critical thinking, academic achievement, or collaborative learning independently. Results presented here complement these approaches by integrating conceptual understanding, cognitive engagement, teacher scaffolding, collaborative inquiry, self-regulated learning, and classroom climate into a unified explanatory framework. Such integration provides a broader understanding of why PBL produces sustainable learning outcomes than studies emphasizing instructional strategy alone.

Differences also emerge regarding the role of teacher guidance during inquiry-based instruction. Existing literature occasionally portrays Problem-Based Learning as emphasizing predominantly independent student exploration. Findings from this study indicate that structured teacher scaffolding significantly strengthens conceptual understanding and cognitive engagement, particularly among primary school learners whose inquiry skills are still developing. Teacher facilitation therefore remains an essential instructional component rather than diminishing learner autonomy.

Current research frequently evaluates short-term improvements in academic performance without fully examining the cognitive mechanisms underlying conceptual change. Findings demonstrate that self-regulated learning partially mediates conceptual development while collaborative inquiry strengthens analytical reasoning and knowledge transfer. Learning processes therefore deserve equal attention alongside outcome measures within future investigations of Problem-Based Learning.

Observed findings indicate that conceptual understanding should be interpreted as an active process of knowledge construction rather than simple acquisition of factual information. Students developed deeper conceptual comprehension because they continuously analyzed authentic problems, evaluated evidence, discussed alternative explanations, and reflected upon their reasoning. Meaningful conceptual learning therefore emerges through intellectual engagement with realistic educational challenges.

Problem-solving ability similarly appears to develop through reciprocal interaction among conceptual understanding, collaborative inquiry, teacher guidance, and reflective thinking. Students gradually became capable of transferring classroom knowledge to unfamiliar situations because learning experiences emphasized reasoning rather than memorization. Cognitive flexibility consequently represents an important outcome of inquiry-oriented instruction.

Teacher engagement emerges as another significant indicator of successful Problem-Based Learning implementation. Students consistently demonstrated stronger conceptual understanding and greater confidence when teachers provided appropriate scaffolding, facilitated discussion, encouraged questioning, and supported reflective learning without directly supplying solutions. Effective teaching therefore balances instructional guidance with learner autonomy.

Institutional support also appears essential because sustainable implementation of Problem-Based Learning requires collaborative curriculum planning, professional development, supportive leadership, authentic assessment, and positive classroom culture. Instructional innovation consequently reflects organizational educational capacity rather than individual teacher effort alone.

Scientific implications suggest that future educational research should investigate inquiry-based learning through integrated cognitive, social, and instructional frameworks rather than focusing exclusively on academic achievement. Conceptual understanding, metacognition, collaborative inquiry, and instructional support collectively explain meaningful learning more comprehensively than isolated cognitive variables. Broader theoretical models are therefore required to strengthen contemporary educational psychology.

Educational implications encourage primary schools to integrate authentic problem-solving, collaborative inquiry, reflective discussion, formative assessment, and teacher scaffolding throughout curriculum implementation. Classroom instruction should prioritize conceptual reasoning, evidence-based inquiry, and meaningful application of knowledge rather than emphasizing procedural repetition and factual memorization. Such pedagogical transformation supports long-term cognitive development.

Practical implications extend to teachers, curriculum developers, school leaders, and policymakers responsible for improving instructional quality. Findings indicate that sustained professional development in Problem-Based Learning, inquiry facilitation, authentic assessment, and collaborative instructional planning may substantially improve students' conceptual understanding and problem-solving competence. Organizational commitment consequently becomes a major determinant of successful instructional innovation.

Societal implications include preparing children with analytical reasoning, adaptability, collaboration, creativity, and lifelong learning competencies required within increasingly complex social and technological environments. Schools implementing comprehensive inquiry-based learning frameworks may contribute to developing future citizens capable of addressing authentic problems through critical, ethical, and evidence-based decision-making.

Improved learning outcomes primarily resulted from instructional experiences requiring students to construct conceptual understanding through direct engagement with authentic problems. Inquiry activities encouraged learners to activate prior knowledge, evaluate evidence, formulate explanations, and continuously refine conceptual understanding through collaborative reasoning. Knowledge construction therefore became deeper and more transferable than learning based primarily upon procedural practice.

Collaborative learning further contributed by exposing students to diverse perspectives, encouraging dialogue, supporting shared reasoning, and facilitating collective problem-solving. Continuous interaction with peers strengthened communication, reflection, and conceptual clarification while reducing misconceptions through cooperative inquiry. Social interaction consequently became an important mechanism supporting cognitive development.

Teacher scaffolding substantially enhanced intervention effectiveness because educators intentionally guided inquiry without replacing students' independent reasoning. Strategic questioning, formative feedback, conceptual clarification, and reflective discussion enabled learners to overcome cognitive challenges while maintaining responsibility for constructing their own understanding. Instructional guidance therefore promoted both independence and conceptual accuracy.

Supportive classroom climate and institutional leadership collectively sustained these improvements by providing sufficient instructional time, collaborative lesson planning, professional development, authentic assessment practices, and organizational encouragement for inquiry-based education. Consistent educational support ensured coherent implementation across learning activities while reinforcing students' engagement with meaningful problem-solving experiences.

Future investigations should examine the long-term sustainability of conceptual understanding and problem-solving competence through longitudinal studies following students across multiple educational stages. Extended observation would clarify whether inquiry-based learning continues influencing higher-order thinking, academic achievement, learning autonomy, and transfer of knowledge beyond primary education. Longitudinal evidence would strengthen understanding of developmental processes supporting meaningful learning.

Comparative research involving early childhood education, secondary schools, inclusive classrooms, rural schools, and culturally diverse educational contexts deserves continued attention because Problem-Based Learning may operate differently across developmental levels and institutional environments. Comparative evidence would support adaptation of inquiry-based instructional models appropriate for diverse educational settings.

Emerging educational technologies, including artificial intelligence-supported tutoring, digital simulations, virtual laboratories, augmented reality, collaborative online inquiry, and adaptive learning systems, provide valuable opportunities for strengthening Problem-Based Learning implementation (Nimitbunanan et al., 2025). Future studies should investigate how technology-enhanced inquiry complements face-to-face instruction while maintaining authentic collaboration and conceptual understanding.

Interdisciplinary collaboration among educational psychologists, curriculum specialists, cognitive scientists, instructional designers, classroom teachers, school leaders, and policymakers will remain essential for advancing inquiry-based education (Adamu et al., 2025). Continued integration of cognitive theory, instructional innovation, authentic assessment, and educational leadership will contribute substantially to developing primary education systems that cultivate conceptual understanding, analytical reasoning, and lifelong problem-solving competence.

CONCLUSION

Findings demonstrate that Problem-Based Learning significantly enhances conceptual understanding and problem-solving skills among primary school students by integrating authentic inquiry, collaborative learning, reflective thinking, and structured teacher scaffolding into classroom instruction. Distinctive evidence from this study indicates that conceptual understanding functions as the primary cognitive mechanism through which Problem-Based Learning improves problem-solving performance, while self-regulated learning and cognitive engagement reinforce this relationship. Teacher scaffolding emerged as a critical instructional factor that strengthened students' inquiry processes without reducing learner autonomy, enabling children to construct deeper conceptual knowledge and transfer their understanding to unfamiliar problem situations. These findings suggest that meaningful cognitive development in primary education results from the reciprocal interaction among inquiry-based pedagogy, conceptual knowledge construction, collaborative learning, and supportive instructional environments rather than from procedural instruction alone.

Scientific contribution of this study extends both conceptually and methodologically. Conceptually, the research proposes an integrated framework combining constructivist learning theory, cognitive psychology, educational psychology, inquiry-based learning, collaborative learning, and self-regulated learning to explain how Problem-Based Learning simultaneously strengthens conceptual understanding and problem-solving competence. Methodologically, the mixed-methods sequential explanatory design integrates quasi-experimental intervention, repeated-measures analysis, generalized linear mixed-effects modeling, structural equation modeling, mediation and moderation analyses, qualitative interviews, classroom observations, and instructional document analysis to examine both measurable cognitive outcomes and contextual instructional processes. Integration of quantitative and qualitative evidence provides a comprehensive understanding of inquiry-based learning while offering practical guidance for designing effective Problem-Based Learning programs in primary education.

Scope of this investigation remains limited to primary schools implementing structured Problem-Based Learning within relatively supportive instructional and organizational contexts, thereby limiting direct generalization to educational settings with different curriculum structures, teacher expertise, resource availability, or institutional capacity. Variations in socioeconomic conditions, cultural contexts, educational policies, digital infrastructure, and classroom diversity may influence the effectiveness of inquiry-based instruction across broader educational environments. Future research should therefore undertake longitudinal, comparative, and cross-cultural investigations involving early childhood education, secondary schools, inclusive classrooms, technology-enhanced inquiry environments, and artificial intelligence-supported Problem-Based Learning while examining long-term conceptual development, knowledge transfer, creativity, and collaborative problem-solving across diverse educational contexts.

DECLARATION OF AI AND AI ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this manuscript, the author(s) used Grammarly to assist in improving grammar, language quality, and overall readability of the text. After using this tool, the author(s) carefully reviewed and edited the content as necessary and take full responsibility for the content of the publication.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; In-vestigation.

Author 3: Data curation; Investigation.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Abaei, S., Vaez, H., Ghaffarifar, S., Kabiri, N., Mehdipour, R., & Omranifar, D. (2024). Pharmacology Teaching Methods and Affective Factors in Their Success in Educating Undergraduate Medical Students: A Scoping Review. *Strides in Development of Medical Education*, *21*(1). https://doi.org/10.22062/sdme.2024.199197.1308

Adamu, I., Khan, M. S. H., & Hasan, M. (2025). Engineering Students' Experience on Project-Based Learning: A phenomenographic investigation. *2025 10th International STEM Education Conference (iSTEM-Ed)*, 1–6. https://doi.org/10.1109/iSTEM-Ed65612.2025.11129327

Alpuche De Lille, M. J., Teixeira Da Silva, R., & Smythe, T. (2025). School-based mental health and psychosocial support interventions for children and adolescents with developmental disabilities in low- and middle-income countries: A systematic review. *Tropical Medicine & International Health*, *30*(8), 763–781. https://doi.org/10.1111/tmi.70000

Alvidrez, M., Wayllace, C., & Castillo, R. T. (2024). WIP: SABERR, A Structured Error-Based Assessment in AI Education. *2024 IEEE Frontiers in Education Conference (FIE)*, 1–5. https://doi.org/10.1109/FIE61694.2024.10893087

Bani-Hamad, A. M. H., & Al-Kalbani, M. S. A. (2024). Fermi Problem-Based Learning with Artificial Intelligence: Is It Effective to Develop United Arab Emirates Cycle Three Students' Twenty-First Century Skills? In A. Al-Marzouqi, S. A. Salloum, M. Al-Saidat, A. Aburayya, & B. Gupta (Eds.), *Artificial Intelligence in Education: The Power and Dangers of ChatGPT in the Classroom* (Vol. 144, pp. 113–125). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-52280-2_8

Baptista, M., Pinho, A. S., & Alves, A. R. (2025). Students' Learning for Action Through Inquiry-Based Science Education on a Local Environmental Problem. *Sustainability*, *17*(9), 3907. https://doi.org/10.3390/su17093907

Barradas, R., Lencastre, J. A., Soares, S. P., & Valente, A. (2024). Arduino-Based Mobile Robotics for Fostering Computational Thinking Development: An Empirical Study with Elementary School Students Using Problem-Based Learning Across Europe. *Robotics*, *13*(11), 159. https://doi.org/10.3390/robotics13110159

Bendeliani, N., & Torstensdotter, G. L. (2026). The role of the "problem" in problem-based learning: PBL tutors' conceptions. *Scandinavian Journal of Educational Research*, 1–14. https://doi.org/10.1080/00313831.2026.2625211

Berg, K. E. C., Lundgren, J. S., & Bernhardsson, S. (2024). Facilitators and barriers for implementing the PALS school-wide positive behavior support model in a Swedish municipality: A focus group study. *Scandinavian Journal of Psychology*, *65*(5), 919–936. https://doi.org/10.1111/sjop.13045

Ceytlin, S. N., & Kruglyakova, T. A. (2024). Case system in learning Russian as a first and second foreign language. *Russian Language Studies*, *22*(1), 135–149. https://doi.org/10.22363/2618-8163-2024-22-1-135-149

Chen, S.-J., Chen, C.-Q., & Shan, X.-F. (2024). The Effects of an Immersive Virtual-Reality-Based 3D Modeling Approach on the Creativity and Problem-Solving Tendency of Elementary School Students. *Sustainability*, *16*(10), 4092. https://doi.org/10.3390/su16104092

Chen, Y., Zhao, Y., & Wang, M. (2024). An Empirical Study on the Effect of Gamified Teaching in Scratch Courses on Developing Elementary Students' Computational Thinking. *2024 13th International Conference on Educational and Information Technology (ICEIT)*, 78–83. https://doi.org/10.1109/ICEIT61397.2024.10541025

Cheng, G., Wong, W., Luo, L., & Yu, M. (2025). Integrating a Scaffolding-Based, LLM-Driven Chatbot into Programming Education: A University Case Study. *2025 International Symposium on Educational Technology (ISET)*, 1–5. https://doi.org/10.1109/ISET65607.2025.00047

Costa, G., De Francisci, S., Renieri, M., & Valiani, S. (2025). Tackling the Gender Gap in Cybersecurity Education. *Proceedings of the 56th ACM Technical Symposium on Computer Science Education V. 1*, 234–240. https://doi.org/10.1145/3641554.3701807

Elov, B., Samatov, M., Gayibova, N., Samadova, N., Qodirova, M., & Amirovich, S. (2024). A Mantle of Chatbots in the Place of Pedagogy and Learning to Generate Tools to Provide Assistance using A-I. *2024 4th International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE)*, 1075–1079. https://doi.org/10.1109/ICACITE60783.2024.10617382

Fabre, N., & Vinyoles, D. (2024). Mejorando un cuento ambiental sobre las anguilas. Cómo la presencia de animales vivos y materiales interactivos incrementa la atención y la participación. *Revista Eureka Sobre Enseñanza y Divulgación de Las Ciencias*. https://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2024.v21.i1.1501

Garcia-Chitiva, M. D. P., & Correa, J. C. (2024). Soft skills centrality in graduate studies offerings. *Studies in Higher Education*, *49*(6), 956–980. https://doi.org/10.1080/03075079.2023.2254799

García-Hermoso, A. (Ed.). (2024). *Promotion of Physical Activity and Health in the School Setting*. Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-65595-1

Gelmez Burakgazi, S., & Reiss, M. J. (2024). Perceptions of Sustainability among Children and Teachers: Problems Revealed via the Lenses of Science Communication and Transformative Learning. *Sustainability*, *16*(11), 4742. https://doi.org/10.3390/su16114742

Guarcello, E., & Longo, A. (2024). International call for AI Ethics. In E. Guarcello & A. Longo, *School Children and the Challenge of Managing AI Technologies* (1st ed., pp. 201–209). Routledge. https://doi.org/10.4324/9781032694283-21

Korukire, N., Godson, A., Mukamurigo, J., De Dieu Habimana, J., Josias, I., & Ntakirutimana, T. (2025). Effects of indoor air pollution exposure on lung function of children in selected schools in Kigali, Rwanda. *Scientific Reports*, *15*(1), 13617. https://doi.org/10.1038/s41598-025-92047-z

Liu, J., Keane, T., Sun, D., Yang, Y., & Yang, Y. (2025). Design and evaluation of ChatGPT-MWPS: An AI-enhanced learning system for improving primary students' mathematical word problem solving. *Smart Learning Environments*, *12*(1), 68. https://doi.org/10.1186/s40561-025-00419-9

Liu, Y., Ma, Z., Ng, J. T. D., & Hu, X. (2025). Multimodal learning analytics for game-based assessment of collaborative problem solving skills among young students. *Proceedings of the 15th International Learning Analytics and Knowledge Conference*, 963–969. https://doi.org/10.1145/3706468.3706555

Lozano-Monterrubio, N., Cuartielles, R., Carrillo-Pérez, N., & Montagut, M. (2024). Escape rooms como metodología educativa para combatir la desinformación en alumnos de primaria y secundaria: El caso de Learn to Escape. *Revista Latina de Comunicación Social*, (82). https://doi.org/10.4185/rlcs-2024-2243

Murphy, M. C. (2025). A Bio-Ecological Exploratory Case Study of the Forest School Approach to Learning and Teaching in the Irish Primary School Curriculum. In T. Gray, M. Sturges, & J. Barnes (Eds.), *Risk and Outdoor Play* (pp. 195–218). Springer Nature Singapore. https://doi.org/10.1007/978-981-96-5455-0_12

Nimitbunanan, P., Lertbutsayanukul, N., & Korkiatkrai, S. (2025). Artificial Intelligence Assisted Histology Learning for High School students in Thailand by using Deep Learning Models as Tools for Interdisciplinary STEM Engagement. *2025 10th International STEM Education Conference (iSTEM-Ed)*, 1–6. https://doi.org/10.1109/iSTEM-Ed65612.2025.11129423

Norwich, B., Baumfield, V., Dimitrellou, E., Katene, W., & Koutsouris, G. (2025). Exploring reflective practice through lesson study in the school-based practices of PGCE primary and secondary student teachers in a UK ITE programme. *Reflective Practice*, *26*(4), 511–527. https://doi.org/10.1080/14623943.2025.2459435

Pektaş, H. M., & Karamustafaoğlu, S. (2025). 5E Enriched With Technology-Supported Conceptual Change Tools: The Effect on Conceptual Change Level and Creative Problem Solving Skills of Gifted Students. *School Science and Mathematics*, ssm.18394. https://doi.org/10.1111/ssm.18394

Ramaila, S. (2026). Utilizing GeoGebra as an Interactive Digital Tool to Enhance Effective Mathematics Teaching and Learning: A Systematic Review. *Journal of Research in Mathematics Education*, *15*(2), 106–124. https://doi.org/10.17583/redimat.15749

Shykyrynska, O., Liapunova, V., Melnykova, O., Mnyshenko, K., & Petryshyna, T. (2024). READINESS OF THE FUTURE PRESCHOOL AND PRIMARY EDUCATION SPECIALISTS TO FORM THE FOUNDATIONS OF CHILDREN'S CYBER SECURITY. *ENVIRONMENT. TECHNOLOGY. RESOURCES. Proceedings of the International Scientific and Practical Conference*, *2*, 481–484. https://doi.org/10.17770/etr2024vol2.8087

Sirisathitkul, C., Sirisathitkul, Y., Wattanasit, K., & Nisoa, M. (2026). Converging *objects-to-think-with*: Exploring microwave ovens through inquiry-based learning with ChatGPT. *Research in Science & Technological Education*, *44*(2), 829–845. https://doi.org/10.1080/02635143.2025.2496990

Tasić, N., Glušac, D., Makitan, V., Jokić, S., Ljubojev, N., & Vignjević, K. (2025). Promoting Sustainable Education Through the Educational Software Scratch: Enhancing Attention Span Among Primary School Students in the Context of Sustainable Development Goal (SDG) 4. *Sustainability*, *17*(20), 9292. https://doi.org/10.3390/su17209292

Trudel-Ferland, M., Ghodbane, A., Yoshida, M., Kouki, A. B., Lina, J. M., Deslandes, D., & Zhuldybina, M. (2025). CoulombCompagnon: An intelligent tutoring system for enhancing electromagnetic concepts understanding in engineering education. In A. Kallepalli (Ed.), *Education and Training in Optics and Photonics: ETOP 2025* (p. 64). SPIE. https://doi.org/10.1117/12.3076852

Wahyuni, Y., Fauzan, A., Yerizon, Y., Arnawa, I. M., Irfan, D., & Rasli, A. (2025). Enhancing Creative Mathematical Thinking with GeoGebra: A Comparative Study of Secondary School Students. *Salud, Ciencia y Tecnología*, *5*, 1435. https://doi.org/10.56294/saludcyt20251435

Xu, T., Ge, X., Gao, Q., & Lu, J. (2025). The impact of STEAM project design on higher-order thinking: A meta-analysis. *Research in Science & Technological Education*, 1–25. https://doi.org/10.1080/02635143.2025.2533194

Yang, K.-K. (2025). Exploring primary school students drawing solutions to problems in STEM activities. *Thinking Skills and Creativity*, *56*, 101790. https://doi.org/10.1016/j.tsc.2025.101790

Yulianti, E., Abdul Rahman, N. F., Suwono, H., & Phang, F. A. (2026). Transdisciplinary STEAM learning in improving students' conceptual understanding of heat and temperature. *Research in Science & Technological Education*, *44*(1), 117–137. https://doi.org/10.1080/02635143.2025.2452542

Zhang, Y., Wu, H., Ma, R., Feng, B., Yang, R., Chen, X., Li, M., & Cheng, L. (2025). Machine Learning-Based predictive model for adolescent metabolic syndrome: Utilizing data from NHANES 2007–2016. *Scientific Reports*, *15*(1), 3274. https://doi.org/10.1038/s41598-025-88156-4