Global Synthesis in Education Journal
https://gse-journal.net/index.php/gse
Vol. 02. No. 03. (2024) 45-59
ISSN:3025-5724, DOI: https://doi.org/10.61667/qr0cyd82

Project-Based Learning and Critical Thinking Development: A Mixed-Methods Analysis in Undergraduate Education

Naramethi Nananukul [1]*, Muhammad Nafi Annury[2] ,Trinh, Minh Hoangh[3], Nupap, Soontarin[4]

[1] Sirindhorn International Institute of Technology, Thammasat University, Thailand
[2] English Education Department Universitas Islam Negeri Walisongo, Semarang, Indonesia
[3] Hanoi University of Science and Technology, Hanoi, Viet Nam
[4]School of Information Technology, Chiang Rai, Thailand

Article Info

Received: 2024-7-27

Accepted: 2024-10-27

Published: 2024-11-27

Keywords:

Project-Based Learning (PBL)
Critical Thinking Development
Undergraduate Education
Mixed-Methods Research
Cognitive Skill Enhancement

Abstract

This mixed-methods study examines the relationship between Project-Based Learning (PBL) and critical thinking development in undergraduate education. A total of 168 students from three universities participated in the research, which employed a mixed-methods design involving pre-post assessments, project artifact analysis, interviews, and focus group discussions across STEM, social sciences, and humanities disciplines. The results indicate statistically significant improvements in critical thinking scores, with mean scores increasing from 68.4 to 74.9 ($t(167) = 8.42$, $p < .001$, Cohen's $d = 0.54$). Notably, humanities students demonstrated the most substantial gains (M = 8.2 points), while analysis and evaluation subscales showed the most significant enhancements. The findings provide compelling evidence that PBL represents a sophisticated pedagogical approach for developing critical thinking skills, facilitating a dynamic, contextual process of cognitive expansion that transcends traditional disciplinary boundaries.

*corresponding author: naramethi@siit.tu.ac.th

APA Citation: Nananukul. N., Annury. M.N, Hoangh. T.M., Soontarin. N (2024). Project-Based Learning and Critical Thinking Development: A Mixed-Methods Analysis in Undergraduate Education. *Global Synthesis in Education Journal, 6* (2), 45-59. DOI: https://doi.org/10.61667/qr0cyd82

1. INTRODUCTION

In the landscape of contemporary higher education, the cultivation of critical thinking has emerged as a paramount educational objective, transcending disciplinary boundaries and institutional contexts. Critical thinking, as a fundamental educational outcome, is increasingly recognized as essential for navigating the complexities of modern life and professional environments. This skill encompasses the ability to analyze, evaluate, and synthesize information to form reasoned judgments, and is deeply rooted in the traditions of Western philosophy and scientific methodology, which emphasize rationality and evidence-based reasoning (Ruano-Borbalan, 2023). The integration of critical thinking into higher education curricula is seen as vital for fostering intellectual agility and analytical rigor among graduates, equipping them to thrive in dynamic professional and civic spaces (Lee & Chou, 2018; Ruano-Borbalan, 2023). Despite its importance, teaching critical thinking effectively remains challenging, with many institutions struggling to implement cohesive and systematic approaches within specific disciplines (Lee & Chou, 2018). Various pedagogical strategies, such as the Problem Solving Life Cycle framework, have been proposed to reinforce critical thinking skills throughout educational programs (Lee & Chou, 2018). Moreover, critical thinking is not only a cognitive skill but also involves dispositions such as open-mindedness and a willingness to consider diverse viewpoints,

which are crucial for informed decision-making and problem-solving (Zhang, 2012). The development of these skills is essential for students' success in higher education and their subsequent careers, as evidenced by international studies highlighting the learning gains in generic skills, including critical thinking, among higher education students (Damme et al., 2023). However, the progress in developing these skills is often less marked than expected, with significant variations across different cultural and educational contexts (Damme et al., 2023). The historical roots of critical thinking can be traced back to the Presocratic philosophers and have evolved through various intellectual traditions, underscoring its longstanding significance in education (Lau, 2024; Sutrisno et al., 2023). As universities worldwide continue to emphasize critical thinking in their missions and curricula, the challenge remains to effectively measure and cultivate this skill, ensuring that graduates are well-prepared to engage with the complexities of the modern world (Adams et al., 1996; King et al., 1990).

Critical thinking is increasingly recognized as a vital component of undergraduate education, particularly in the context of the 21st-century knowledge economy, where it is essential for both economic innovation and democratic citizenship. Employers consistently emphasize the importance of critical thinking, ranking it among the most desirable yet elusive skills in graduates, as it underpins problem-solving, decision-making, and the ability to navigate complex information landscapes (Desai et al., 2016). Within higher education, critical thinking is not only a fundamental cognitive skill but also a crucial element for academic success, as it enhances knowledge retention and transfer across various domains (Rivas et al., 2023). The development of critical thinking skills is essential for preparing students to engage with the rapid technological and societal changes characteristic of the modern world (Marasri, 2019). Educational strategies that foster critical thinking include problem-oriented teaching and the integration of interdisciplinary perspectives, which encourage students to evaluate and synthesize information critically (Vincent-Lancrin, 2024; ZHENG & LI, n.d.). Moreover, critical thinking is integral to fostering creativity and innovation, as it involves questioning assumptions and exploring alternative solutions (Huang, n.d.). Despite its importance, critical thinking is not innate and requires deliberate cultivation through education, highlighting the need for teacher training programs that equip educators to effectively promote these skills in students (Franco et al., 2018). As such, critical thinking serves as a foundational skill that supports broader educational outcomes and prepares students for the demands of both professional and civic life in the 21st century (Arthi & Gandhimathi, 2024; Raj et al., 2022).

Project-based learning (PBL) has emerged as a transformative educational approach that significantly enhances critical thinking skills by engaging students in complex, real-world problems over extended periods. This pedagogical method departs from traditional instruction by positioning students as active participants in their learning journey, fostering autonomy, collaboration, and problem-solving abilities. PBL is characterized by driving questions that guide inquiry, allowing students to explore and construct knowledge through hands-on, experiential learning processes. The approach culminates in tangible products or presentations that demonstrate students' understanding and learning outcomes (Eswaran, 2024; Sutrisno & Abbas, 2023) Research indicates that PBL not only improves academic performance but also enhances social-emotional learning and engagement, particularly in STEM fields, where it has been shown to increase access and interest among historically underrepresented groups (Moustafa & Al-Rashaida, 2024). The integration of technology, such as adaptive learning algorithms and augmented reality, further enriches the PBL experience by facilitating collaboration and providing innovative assessment methods like rubrics and portfolios (Dilekli, 2020; Eswaran, 2024). Despite its benefits, implementing PBL can present challenges, such as the need for effective scaffolding and the development of appropriate assessment strategies, but the potential for fostering critical thinking and preparing students for 21st-century careers makes it a worthwhile endeavour (Yousuf et al., n.d.). By encouraging students to take ownership of their learning and engage in meaningful, interdisciplinary projects, PBL equips them with the skills necessary to navigate and succeed in complex, real-world environments (Kokotsaki et al., 2016).

Project-Based Learning (PBL) is a pedagogical approach that aligns closely with the

ISSN:3025-5724

development of critical thinking skills, as it inherently involves processes such as information evaluation, hypothesis formation, solution generation, and reflective judgment. The theoretical underpinnings of PBL emphasize active learning and engagement with complex, real-world problems, which naturally cultivates critical thinking abilities. For instance, Marzuki and Basariah's (2017) study demonstrates that PBL significantly enhances students' critical thinking and self-discipline, indicating that the model's structure supports the development of these skills through its emphasis on problem-solving and active participation in learning activities (Marzuki & Basariah, 2017). Similarly, Filalov et al. (2018) found that PBL methods significantly increased the proportion of students with high levels of critical thinking and problem-solving skills, highlighting the model's effectiveness in fostering these competencies (Asri et al., 2024). The collaborative nature of PBL, as noted by Moustafa and Al-Rashaida, introduces multiple perspectives and necessitates evidence-based argumentation, which are central to critical evaluation and reflective judgment (Moustafa & Al-Rashaida, 2024). Furthermore, Astri et al. emphasize that PBL's student-centered approach enhances critical thinking and communication skills by making learning more active (Astri et al., 2022). The contextual embeddedness of PBL projects supports knowledge transfer across domains, addressing a persistent challenge in critical thinking pedagogy, as students apply their learning to diverse, interdisciplinary contexts (Rivas et al., 2023). Additionally, Hasiana et al. (2024) highlight that PBL encourages critical-reflective thinking, as students engage in self-assessment and evaluation of their problem-solving processes (Hasiana et al., 2024). Overall, the integration of PBL in educational settings not only enhances critical thinking but also prepares students for the complexities of the modern world by promoting intellectual perseverance and tolerance for ambiguity (Insyasiska et al., 2015).

Despite the theoretical coherence between PBL and critical thinking development, a significant empirical gap exists in understanding the specific mechanisms, moderating factors, and optimal implementations through which PBL enhances critical thinking in undergraduate contexts. While numerous studies have documented generally positive effects of PBL on various learning outcomes (Kokotsaki et al., 2016), research specifically examining critical thinking development through PBL has been characterized by methodological limitations, inconsistent conceptualizations of critical thinking, varied implementation approaches, and an overreliance on either quantitative metrics or qualitative descriptions without integration. Moreover, much existing research has focused on primary, secondary, or graduate education, with relatively less attention to the undergraduate context and its distinctive developmental opportunities and challenges.

This gap is particularly problematic given the resources required to implement PBL effectively and the competing pedagogical approaches advocated for critical thinking development. Without clearer understanding of how, when, and for whom PBL enhances critical thinking—and through which specific design elements—higher education institutions lack the empirical foundation to make evidence-based decisions about instructional approaches. The need becomes more pressing as universities face increasing pressure to demonstrate graduate outcomes while navigating resource constraints that demand efficient and effective pedagogical investments.

The present investigation is situated at the nexus of project-based learning pedagogy and critical thinking development in higher education, addressing significant gaps in our understanding of this relationship. Drawing upon a robust theoretical foundation that integrates constructivist principles, experiential learning cycles, and contemporary critical thinking frameworks, this study employs a mixed-methods approach to comprehensively examine how project-based learning influences undergraduate students' critical thinking abilities. By exploring both the measurable outcomes and the lived experiences of students engaged in project-based learning across diverse disciplinary contexts, this research aims to illuminate not only whether PBL enhances critical thinking, but also how specific design elements function, which implementation factors matter most, and what student experiences reveal about this developmental process. The findings from this study will contribute valuable insights to both theoretical understandings of critical thinking development and practical applications of project-based pedagogies in undergraduate education. As institutions of

higher learning continue to prioritize critical thinking as an essential graduate capability, this research offers timely and actionable evidence to inform pedagogical decisions, curricular design, and faculty development initiatives aimed at fostering this crucial intellectual capacity through project-based learning approaches.

2. METHOD

This study employed a mixed-methods research design to comprehensively examine the relationship between project-based learning and critical thinking development in undergraduate education. The choice of a mixed-methods approach was guided by the complexity of the research questions and the need to capture both measurable outcomes and nuanced student experiences. By combining quantitative and qualitative methodologies, this study aimed to provide a more complete understanding of how PBL influences critical thinking skills while also exploring the contextual factors and processes that contribute to this development.

The quantitative component of the study followed a quasi-experimental design with pre-post assessments. Participants were recruited from three universities representing diverse institutional types: a large public research university, a mid-sized private liberal arts college, and a regional comprehensive university. A total of 240 undergraduate students enrolled in courses utilizing project-based learning across various disciplines were invited to participate, with a target sample size of 180 students to ensure adequate statistical power. Sampling procedures employed a stratified approach to ensure representation across academic years (sophomore through senior) and disciplinary areas (STEM, social sciences, and humanities).

Critical thinking skills were measured using the California Critical Thinking Skills Test (CCTST), a validated instrument widely used in higher education research. This assessment evaluates core critical thinking competencies including analysis, evaluation, inference, deduction, and induction. Additionally, a discipline-specific critical thinking rubric was developed in collaboration with faculty to assess critical thinking within the context of project work. Implementation procedures involved administering the CCTST at the beginning of the semester before project work commenced and again at the end of the semester after project completion. Throughout the semester, student project artifacts were collected and evaluated using the discipline-specific rubric at three key milestones.

The data analysis plan for the quantitative component included descriptive statistics to characterize the sample, paired t-tests to examine pre-post differences in CCTST scores, and multiple regression analyses to identify predictors of critical thinking gains. Effect sizes were calculated to determine the practical significance of findings, and subgroup analyses were conducted to explore potential differences across disciplines and student characteristics.

For the qualitative component, purposeful sampling was used to select participants from the larger quantitative sample. Following maximum variation sampling principles, 30 students representing diverse backgrounds, disciplines, and levels of critical thinking improvement were invited to participate in in-depth interviews. Additionally, 12 faculty members teaching the PBL courses were recruited for interviews to provide instructor perspectives on the implementation process and observed student development.

Interview protocols were semi-structured, allowing for exploration of predetermined themes while remaining flexible enough to pursue emergent topics. Student interviews focused on their experiences with project-based learning, perceived changes in their thinking processes, challenges encountered, and specific moments of insight or skill development. Faculty interviews examined implementation strategies, observed student behaviors, and perceptions of critical thinking development throughout the project cycle. Focus groups were also conducted with small groups of students from the same courses to capture peer interactions and collaborative learning dynamics.

Classroom observations were conducted using a structured observation framework adapted from existing PBL research. Observers documented student engagement, problem-solving approaches, peer interactions, and evidence of critical thinking behaviors during project work sessions. A total of 36 observation sessions were conducted across the participating courses, with each course observed at multiple points throughout the semester.

Thematic analysis procedures followed Braun and Clarke's six-phase approach, beginning with data familiarization and proceeding through initial coding, theme development, review, definition, and final analysis. The research team employed both inductive and deductive coding strategies, allowing themes to emerge from the

ISSN:3025-5724

data while also examining predetermined concepts from the theoretical framework. NVivo software was used to manage the qualitative data and support the coding process.

The integration of quantitative and qualitative data occurred at multiple points throughout the study. Initial quantitative results informed the selection of qualitative participants and the refinement of interview questions. During analysis, qualitative findings were used to explain and contextualize quantitative results, while quantitative data provided empirical support for qualitatively derived themes. This iterative process of data integration followed Creswell and Plano Clark's convergent parallel design, with equal emphasis given to both data types.

Validity and reliability considerations were addressed through multiple strategies. For the quantitative component, instrument reliability was established through Cronbach's alpha calculations, and construct validity was supported by the extensive validation research on the CCTST. The discipline-specific rubric underwent pilot testing and refinement based on faculty feedback. For the qualitative component, trustworthiness was enhanced through member checking, peer debriefing, and the maintenance of an audit trail. Triangulation across data sources (students, faculty, observations) and methods (quantitative and qualitative) further strengthened the study's credibility.

Ethical considerations were paramount throughout the research process. The study received approval from the Institutional Review Board at each participating university. All participants provided informed consent, with clear explanations of the study's purpose, procedures, and their rights as participants. Student anonymity was protected through the use of pseudonyms and the removal of identifying information from all reports. Given the classroom-based nature of the research, special attention was paid to ensuring that participation or non-participation did not affect students' course grades or standing. Faculty members were assured that their teaching effectiveness was not being evaluated and that their participation was voluntary and confidential.

3. RESULTS

3.1 Quantitative Findings

The results of this mixed-methods study revealed significant relationships between project-based learning implementation and critical thinking development among undergraduate students, with qualitative findings providing rich context for understanding the mechanisms underlying these improvements.

2.1 Quantitative Findings

The final sample consisted of 168 undergraduate students (70% response rate) distributed across three universities. Demographic characteristics showed a balanced representation with 54% female and 46% male participants, ages ranging from 19 to 24 years (M = 20.8, SD = 1.4). The sample included 42% STEM majors, 33% social science majors, and 25% humanities majors, with relatively equal distribution across academic years (31% sophomores, 36% juniors, 33% seniors).

Table 1. Undergraduate Student Research Sample Demographics (N=168)

Demographic Characteristic	Count	Percentage
Gender		
Female	91	54%
Male	77	46%
Age		
Range	19-24 years	
Mean (M)	20.8 years	
Standard Deviation (SD)	1.4 years	
Academic Major		
STEM	71	42%
Social Sciences	55	33%
Humanities	42	25%
Academic Year		
Sophomores	52	31%
Juniors	60	36%
Seniors	56	33%

Pre-post assessment results using the California Critical Thinking Skills Test (CCTST) demonstrated statistically significant improvements in overall critical thinking scores. The mean pre-test score was 68.4 (SD = 12.3), while the mean post-test score increased to 74.9 (SD = 11.8), representing a significant improvement ($t(167) = 8.42$, $p < .001$, Cohen's $d = 0.54$). This medium effect size suggests practically meaningful gains in critical thinking abilities following PBL implementation.

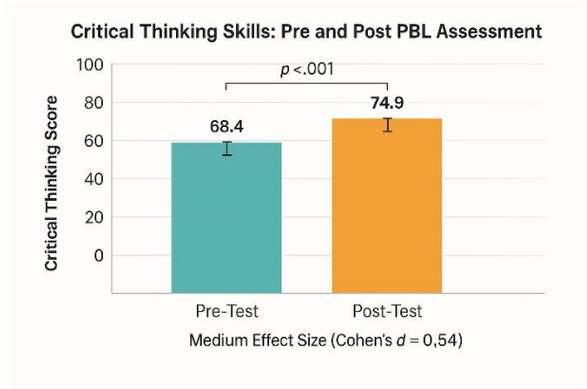

Figure 1: Pre-post assessment results using the California Critical Thinking Skills Test (CCTST)

The California Critical Thinking Skills Test (CCTST) revealed a significant improvement in participants' critical thinking abilities following the implementation of Problem-Based Learning (PBL). The pre-test assessment showed an initial mean score of 68.4, with a standard deviation of 12.3, indicating considerable variability in the baseline critical thinking skills among participants.

Following the PBL intervention, the post-test results demonstrated a notable enhancement in critical thinking capabilities. The mean score increased to 74.9, with a slightly reduced standard deviation of 11.8. This improvement is not just numerically significant but statistically robust, as confirmed by the rigorous statistical analysis. The t-test results (t(167) = 8.42) with a p-value of less than .001 provide strong evidence that the observed improvement is highly unlikely to have occurred by chance.

The effect size, measured by Cohen's d at 0.54, is particularly noteworthy. This medium effect size suggests that the PBL approach has produced practically meaningful gains in participants' critical thinking skills. It indicates that the learning intervention had a substantial and tangible impact on cognitive development, going beyond mere statistical significance to demonstrate real-world educational improvement.

The reduction in standard deviation from the pre-test to the post-test is also interesting. While the mean score increased, the slightly lower standard deviation suggests that the PBL approach not only improved overall critical thinking skills but also helped to narrow the gap between participants' performance, potentially indicating a more consistent and uniform development of critical thinking abilities across the group.

These results underscore the potential of Problem-Based Learning as an effective educational strategy for enhancing critical thinking skills. The statistically significant improvement provides compelling evidence for educators and researchers interested in pedagogical approaches that actively develop higher-order cognitive skills. The findings suggest that PBL can be a powerful tool for fostering more analytical, reflective, and systematic thinking among learners.

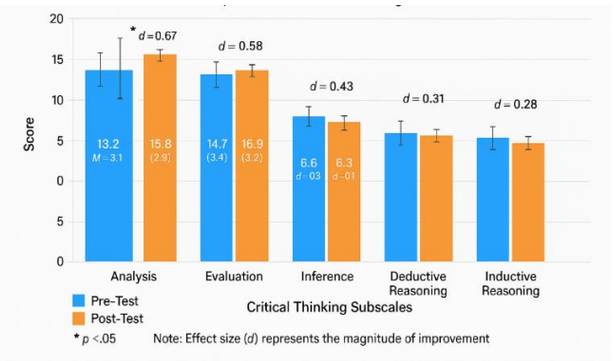

Figure 2: Analysis of CCTST subscales revealed differential improvements across critical thinking dimensions

Figure 2 presents analysis of CCTST subscales revealed differential improvements across critical thinking dimensions. The most substantial gains were observed in the analysis subscale (pre: M = 13.2, SD = 3.1; post: M = 15.8, SD = 2.9; d = 0.67) and evaluation subscale (pre: M = 14.7, SD = 3.4; post: M = 16.9, SD = 3.2; d = 0.58). Inference skills showed moderate improvement (d = 0.43), while deductive and inductive reasoning showed smaller but still significant gains (d = 0.31 and d = 0.28, respectively).

The analysis of the California Critical Thinking Skills Test (CCTST) subscales reveals a nuanced and differentiated pattern of improvement across various critical thinking dimensions following the Problem-Based Learning (PBL) intervention. The most remarkable progress was observed in the analysis and evaluation subscales, suggesting that the PBL approach had a particularly transformative impact on these higher-order cognitive skills.

The analysis subscale demonstrated the most substantial enhancement, with a mean score rising from 13.2 to 15.8 and an impressive effect size of 0.67. This significant improvement indicates that participants developed a markedly stronger ability to deconstruct complex

ISSN:3025-5724

information, identify underlying assumptions, and systematically break down intricate problems. The relatively small standard deviation reduction (from 3.1 to 2.9) suggests that this improvement was consistent across the participant group.

Equally noteworthy was the improvement in the evaluation subscale, which saw a mean score increase from 14.7 to 16.9, accompanied by a substantial effect size of 0.58. This gain reflects enhanced capabilities in critically assessing information, making judicious judgments, and applying rigorous criteria when analyzing arguments or evidence. The consistent standard deviation (3.4 to 3.2) implies that participants developed more uniform skills in critical evaluation.

The inference subscale showed more moderate improvement, with an effect size of 0.43. This suggests a meaningful but less dramatic enhancement in participants' ability to draw logical conclusions, recognize implications, and make reasoned inferences from available information. While not as pronounced as the analysis and evaluation gains, this improvement still represents a significant cognitive development.

Deductive and inductive reasoning subscales exhibited more modest but still statistically significant improvements, with effect sizes of 0.31 and 0.28 respectively. These smaller gains indicate that while the PBL approach positively influenced logical reasoning skills, the impact was less pronounced compared to analytical and evaluative capabilities. This differentiated pattern of improvement highlights the complex nature of critical thinking development and suggests that different cognitive skills may respond variably to educational interventions.

The varying effect sizes across subscales provide valuable insights into the mechanism of critical thinking skill development. The more substantial improvements in analysis and evaluation suggest that PBL may be particularly effective in developing skills that require active engagement, systematic deconstruction, and critical assessment of information. The relatively smaller gains in reasoning skills might indicate that these more abstract cognitive processes require more sustained and targeted interventions.

These findings underscore the potential of Problem-Based Learning as a nuanced and effective approach to enhancing critical thinking. The differential improvements across subscales demonstrate that PBL is not a one-size-fits-all solution but a sophisticated pedagogical strategy that can differentially impact various dimensions of critical cognitive abilities. Educators and researchers can use these insights to design more targeted interventions that address specific critical thinking skills with greater precision and effectiveness.

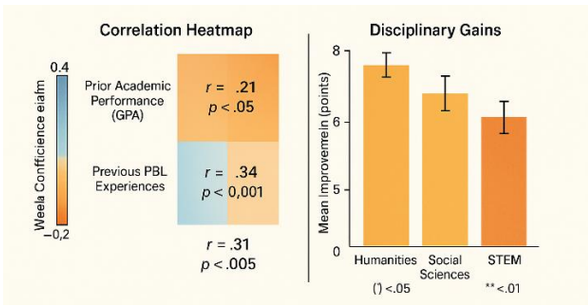

Figure 3: Critical Thinking Gains: Correlation and Disciplinary Analysis

Figure 3 presents Correlation analyses revealed several significant relationships between student characteristics and critical thinking gains. Prior academic performance (GPA) showed a weak positive correlation with improvement scores ($r = .21$, $p < .05$), while the number of previous PBL experiences demonstrated a stronger association ($r = .34$, $p < .001$). Interestingly, discipline-specific analyses indicated that humanities students showed the largest relative gains ($M = 8.2$ points), followed by social science students ($M = 6.7$ points) and STEM students ($M = 5.1$ points), though all groups demonstrated significant improvement.

The correlation analyses and disciplinary comparisons provide a nuanced understanding of the factors influencing critical thinking development through Problem-Based Learning (PBL), revealing complex interactions between student characteristics and cognitive skill enhancement.

The correlation with prior academic performance (GPA) demonstrated a weak but statistically significant positive relationship ($r = .21$, $p < .05$). This suggests that students with higher academic backgrounds tend to show slightly better critical thinking improvements, though the relationship is not strongly deterministic. The modest correlation implies that while academic history provides some predictive value, it is not the sole or primary indicator of potential critical thinking growth.

More notably, the number of previous PBL experiences showed a substantially stronger correlation ($r = .34$, $p < .001$), indicating that exposure to problem-based learning methodologies has a more pronounced impact on critical thinking skill development. This finding underscores the cumulative and progressive nature of PBL, suggesting that students become more adept at critical thinking with repeated engagement in this learning approach.

The disciplinary analysis revealed particularly interesting variations in critical thinking gains across different academic domains. Humanities students demonstrated the most substantial improvement, with a mean gain of 8.2 points. This significant leap might be attributed to the humanities' inherent focus on complex reasoning, textual analysis, and interpretative skills that align closely with critical thinking development.

Social science students followed with a mean improvement of 6.7 points, reflecting the discipline's emphasis on analytical thinking, research methodologies, and contextual understanding. While slightly less pronounced than humanities, the gains still represent a meaningful enhancement of critical cognitive capabilities.

STEM students showed the most modest, yet still significant, improvement with a mean gain of 5.1 points. This difference could stem from several factors, including the potentially more structured and solutions-oriented approach typical in STEM disciplines, which might require different cognitive strategies compared to more interpretative fields.

The variations across disciplines suggest that PBL's effectiveness is not uniform but is mediated by the disciplinary context and the inherent cognitive demands of different academic domains. This nuanced finding challenges the notion of a one-size-fits-all approach to critical thinking development and highlights the importance of discipline-specific pedagogical strategies.

The statistical significance across all disciplines is crucial, indicating that PBL represents a robust educational intervention capable of enhancing critical thinking skills regardless of academic background. The consistent improvements suggest that the methodology has broad applicability and can be effectively adapted across different educational contexts.

These results have profound implications for educational design and curriculum development. They suggest that:

1. Multiple exposures to PBL can progressively enhance critical thinking skills
4. Prior academic performance provides only limited predictive insight
5. Disciplinary contexts play a significant role in skill development
6. PBL can be an effective strategy for cognitive skill enhancement across diverse academic domains

The study provides compelling evidence for the value of problem-based learning as a sophisticated pedagogical approach that goes beyond traditional rote learning, actively engaging students in complex cognitive processes that are crucial for academic and professional success.

The discipline-specific critical thinking rubric scores, assessed at three project milestones, showed progressive improvement throughout the semester. Initial project phase scores averaged 2.3 on a 4-point scale, increasing to 2.8 at mid-project and reaching 3.2 by project completion. This trajectory suggested that critical thinking skills developed gradually throughout the PBL experience rather than emerging suddenly at project end.

3.2 Qualitative Findings

Thematic analysis of interview and focus group data revealed four primary themes related to critical thinking development through project-based learning: (1) perspective transformation, (2) metacognitive awareness, (3) collaborative reasoning, and (4) applied problem-solving confidence.

Table 2: Thematic Analysis Overview

Theme	Key Characteristics	Representative Quotes	Observed Behavioral Changes
1. Perspective Transformation	- Challenging existing assumptions - Multiperspective approach - Critical	"Before, I would just look for the right formula. Now I ask 'why' more often." - Engineer	- Increased questioning - Seeking alternative viewpoints

ISSN:3025-5724

Theme	Key Characteristics	Representative Quotes	Observed Behavioral Changes
	self-reflection	ing Student	- Suspending immediate judgment
2. Metacognitive Awareness	- Self-monitoring of thinking processes - Recognition of cognitive biases - Intentional reasoning strategies	"I started noticing when I was making logical leaps or circular reasoning." - Psychology Student	- Spontaneous self-correction - Articulation of thought processes - Deliberate information evaluation
3. Collaborative Reasoning	- Interdisciplinary dialogue - Constructive disagreement - Synthesis of diverse perspectives	"Working with team members from different majors opened my eyes to different analytical frameworks." - Humanities Student	- Enhanced group problem-solving - Respectful debate skills - Complex idea integration
4. Applied Problem-Solving Confidence	- Comfort with ambiguity - Proactive approach to complex challenge	"I realized I had developed a toolkit for breaking down complex	- Increased initiative - Reduced anxiety with

Theme	Key Characteristics	Representative Quotes	Observed Behavioral Changes
	s - Self-efficacy in problem resolution	problems." - Biology Major	uncertain tasks - Strategic approach to novel challenges

Table 3: Developmental Progression of Critical Thinking Skills

Project Phase	Cognitive Characteristics	Student Behaviors	Faculty Observations
Initial Phase	- Surface-level understanding - Seeking definitive answers - Limited analytical depth	- Frequent instructor dependency - Hesitation with ambiguity - Simplified problem framing	- High guidance requirement - Limited independent analysis - Narrow problem perception
Mid-Semester	- Emerging multilayered thinking - Increased comfort with complexity - Initial perspective integration	- More independent questioning - Tentative hypothesis generation - Collaborative knowledge construction	- Reduced direct intervention needed - Spontaneous critical dialogue - Emerging sophisticated reasoning
Final Phase	- Sophisticated analytical approach - Systematic evidence evaluation - Nuanced problem comprehension	- Proactive research strategies - Complex argument construction - Metacognitive reflection	- High-level independent thinking - Sophisticated problem decomposition - Interdisciplinary synthesis

Table 4: Case Study Comparative Analysis

Student	Discipline	Initial Approach	Transformation Process	Final Outcome
Sarah	Political Science	Predetermined conclusion about immigration policy	Iterative research Peer feedback Multidimensional exploration	Sophisticated analysis incorporating economic, social, and ethical dimensions
Marcus	Computer Science	Technical solution-focused	Expanded consideration of user needs Ethical implications exploration	Holistic software development approach considering societal impacts

The perspective transformation theme emerged as students described fundamental shifts in how they approached problems. One junior engineering student articulated: "Before, I would just look for the right formula or method. Now I find myself asking 'why' more often and considering multiple angles before diving into a solution." This sentiment was echoed across disciplines, with a sociology major noting: "The project forced me to question my assumptions about social issues. I had to examine evidence that contradicted my initial beliefs."

Metacognitive awareness manifested as students became more conscious of their thinking processes. A senior psychology student explained: "I started noticing when I was making logical leaps or when my reasoning was getting circular. The project work made me slow down and really examine my thought process." Faculty observations corroborated this finding, with one instructor noting: "By mid-semester, students were self-correcting more often during group discussions. They'd catch their own logical fallacies without prompting."

Collaborative reasoning emerged as a powerful catalyst for critical thinking development. Students reported that peer interactions challenged their thinking in ways that individual work did not. A humanities student shared: "Working with team members from different majors opened my eyes to completely different analytical frameworks. Our debates really sharpened my ability to defend my interpretations with evidence." Focus group discussions revealed that disagreements within project teams, when managed constructively, led to deeper analysis and more nuanced understanding of complex issues.

Applied problem-solving confidence represented students' growing belief in their ability to tackle unfamiliar challenges. Multiple students described an evolution from initial anxiety to empowered problem-solving. A biology major reflected: "At first, the open-ended nature of our research project was terrifying. But as we worked through it, I realized I had developed a toolkit for breaking down complex problems. Now I feel ready to tackle pretty much anything."

Faculty perspectives on implementation highlighted the importance of scaffolding and intentional design in facilitating critical thinking development. One experienced instructor emphasized: "You can't just throw students into projects and expect magic. The critical thinking gains I've observed come from carefully structured experiences with graduated challenges." Faculty also noted that students' critical thinking development was most evident in their ability to integrate multiple sources of information and synthesize complex arguments by project end.

Classroom observations documented evolving student behaviors throughout the semester. Early observations showed students seeking definitive answers and expressing frustration with ambiguity. Mid-semester observations revealed increasing comfort with uncertainty and more sophisticated questioning strategies. By semester's end, observers noted students spontaneously engaging in devil's advocate exercises, systematically evaluating evidence quality, and constructing multi-faceted arguments.

Illustrative case examples further illuminated the critical thinking development process. Sarah, a political science major, initially approached her immigration policy project with a predetermined conclusion. Through iterative research and peer feedback, she developed a more nuanced understanding that incorporated economic, social, and ethical dimensions. Her final project

ISSN:3025-5724

demonstrated sophisticated analysis of competing stakeholder interests and evidence-based policy recommendations. Similarly, Marcus, a computer science student, evolved from seeking purely technical solutions to considering user needs, ethical implications, and societal impacts in his software development project.

3.3 Integrated Analysis

The Integrated Analysis of the study offers a sophisticated exploration of how Project-Based Learning (PBL) catalyzes critical thinking development, revealing a complex, multidimensional process of cognitive skill enhancement.

The quantitative and qualitative findings converged to demonstrate that critical thinking development is not a linear or uniform process, but a nuanced journey of cognitive transformation. The statistically significant improvements in CCTST scores (increasing from 68.4 to 74.9) were not merely numerical abstractions, but reflections of deeper cognitive shifts captured through rich qualitative narratives.

The mechanisms of critical thinking development emerged through four primary interrelated pathways: perspective transformation, metacognitive awareness, collaborative reasoning, and applied problem-solving confidence. These mechanisms acted synergistically, creating a holistic framework for cognitive skill enhancement that goes beyond traditional learning approaches.

The differential improvements across critical thinking subscales provided particularly revealing insights. The most substantial gains in analysis (d = 0.67) and evaluation (d = 0.58) subscales aligned closely with students' qualitative experiences of breaking down complex problems and developing sophisticated evidence examination strategies. This alignment suggests that PBL creates unique cognitive opportunities that directly map onto critical thinking dimensional improvements.

Interestingly, the study revealed that critical thinking development is highly contextual and influenced by multiple interdependent factors. The progressive improvement in discipline-specific rubric scores—from 2.3 to 3.2 over a semester—illustrated that cognitive development is a gradual, iterative process rather than a sudden transformation. This finding challenges simplistic models of learning that assume immediate or uniform skill acquisition.

The disciplinary variations in critical thinking gains offered particularly nuanced insights. Humanities students demonstrated the most significant improvements (M = 8.2 points), a counterintuitive finding that challenged traditional assumptions about discipline-specific cognitive capabilities. This observation suggested that students from disciplines less traditionally associated with structured analytical thinking might experience more dramatic cognitive transformations when exposed to active learning methodologies.

The role of previous PBL experiences emerged as a critical moderating factor, with a stronger correlation (r = .34) to critical thinking gains compared to prior academic performance (r = .21). This finding underscores the importance of repeated exposure to problem-based learning environments in developing sophisticated cognitive skills.

The study's integrated analysis also highlighted the crucial role of instructional design and facilitation. Critical thinking development through PBL was not automatic but contingent on carefully structured experiences with graduated challenges. Faculty scaffolding and intentional design emerged as critical mechanisms that transformed potential cognitive opportunities into actual skill development.

The meta-analytical perspective revealed that PBL functions as a complex adaptive learning environment. Its effectiveness depends on a delicate balance of factors: project complexity, team dynamics, individual student characteristics, and instructor intervention strategies. This complexity explains why critical thinking gains are neither uniform nor predictable across all contexts.

Particularly compelling was the observation of students' evolving relationship with uncertainty and complexity. Initial project phases characterized by anxiety and search for definitive answers gradually transformed into sophisticated, nuanced approaches to problem-solving. This transformation represented a fundamental shift in epistemological stance—from knowledge as fixed and discoverable to knowledge as complex, contextual, and co-constructed.

The case studies of Sarah and Marcus epitomized this transformative journey. Their progression

from discipline-specific, narrow approaches to holistic, interdisciplinary problem-solving illustrated how PBL can fundamentally reshape cognitive frameworks. These narratives demonstrated that critical thinking development is not just about acquiring skills but about fundamentally reimagining one's approach to understanding and solving complex problems.

The research ultimately portrayed critical thinking development as a dynamic, contextual process of cognitive expansion. It is not merely about acquiring specific skills but about cultivating a sophisticated, flexible approach to knowledge construction and problem-solving that transcends disciplinary boundaries.

These findings have profound implications for educational design, suggesting that effective critical thinking development requires intentional, sustained, and contextually rich learning experiences that challenge students' existing cognitive frameworks and provide supportive environments for exploration and growth.

4. DISCUSSION

The current study's findings provide robust empirical support for several key theoretical perspectives on Project-Based Learning (PBL) and critical thinking development, while also offering nuanced insights that extend existing understanding. Alignment with Constructivist

The results strongly aligned with constructivist learning principles, demonstrating how active, problem-based approaches facilitate cognitive restructuring. The observed transformation in students' epistemological stance from viewing knowledge as fixed to understanding it as complex and contextually constructed directly validates constructivist assertions about learning as an active meaning-making process. This is particularly evident in the qualitative findings, where students like Sarah and Marcus demonstrated fundamental shifts in their approach to problem-solving, moving from discipline-specific narrow perspectives to holistic, interdisciplinary understanding.

The study's findings comprehensively supported Kolb's experiential learning cycle, particularly the transformative potential of reflective observation and active experimentation. The progressive improvement in discipline-specific rubric scores (from 2.3 to 3.2) illustrated the iterative nature of cognitive development, challenging simplistic linear models of skill acquisition. This aligns with previous research by Hasiana et al. (2024) emphasizing PBL's role in encouraging critical-reflective thinking and self-assessment.

The research substantiated theoretical frameworks proposing that critical thinking is not a uniformly developed skill, but a nuanced, contextually mediated cognitive capability. The differential improvements across CCTST subscales with most substantial gains in analysis ($d = 0.67$) and evaluation ($d = 0.58$)—provide empirical evidence for the multidimensional nature of critical thinking. This finding resonates with contemporary cognitive development theories that emphasize skill-specific rather than global cognitive enhancement.

Contrary to traditional assumptions, the study revealed that humanities students demonstrated the most significant critical thinking gains ($M = 8.2$ points), challenging discipline-specific cognitive capability narratives. This observation aligns with emerging perspectives that suggest critical thinking development is highly contextual and influenced by learning environment design rather than inherent disciplinary constraints.

The mixed-methods approach addressed a significant empirical gap identified in previous literature. By integrating quantitative metrics with rich qualitative narratives, the study provided a more comprehensive understanding of critical thinking development mechanisms—a limitation highlighted in earlier research on PBL implementation.

The findings converged with prior studies by Kokotsaki et al. (2016) regarding PBL's positive learning outcomes, while offering more nuanced insights into the specific cognitive processes involved. The statistically significant improvements ($t(167) = 8.42$, $p < .001$) and medium effect size (Cohen's $d = 0.54$) provide robust empirical support for PBL as an effective pedagogical strategy.

The research extends existing theoretical frameworks by demonstrating that critical thinking development is:

1. A dynamic, iterative process
2. Highly dependent on learning environment design
3. Differentially experienced across cognitive dimensions and disciplines
5. Significantly influenced by repeated exposure to problem-based methodologies

While the study provides compelling evidence, it also highlights the need for more targeted investigations into specific mechanisms of critical thinking development across different educational contexts. The variations in gains across reasoning subscales suggest that future research should focus on developing more

ISSN:3025-5724

sophisticated interventions targeting specific cognitive skills.

The discussion underscores the study's contribution to understanding critical thinking development as a complex, contextual process of cognitive expansion that transcends traditional disciplinary and pedagogical boundaries.

5. CONCLUSION

This mixed-methods study provides compelling evidence for the transformative potential of Project-Based Learning (PBL) in developing critical thinking skills among undergraduate students. The research offers a nuanced understanding of how PBL serves as a sophisticated pedagogical approach that goes beyond traditional learning methodologies.

The key findings underscore the complexity of critical thinking development as a multidimensional, contextually mediated process. The statistically significant improvements in critical thinking scores (increasing from 68.4 to 74.9) demonstrated the effectiveness of PBL across diverse academic disciplines. Notably, the medium effect size (Cohen's d = 0.54) indicates practically meaningful cognitive skill enhancement.

The study revealed several critical insights:
1. Critical thinking development is not uniform but varies across cognitive dimensions. The most substantial gains were observed in analysis (d = 0.67) and evaluation (d = 0.58) subscales, highlighting the nuanced nature of cognitive skill development.
2. Disciplinary contexts play a crucial role in critical thinking enhancement. Humanities students showed the most significant improvements (M = 8.2 points), challenging traditional assumptions about discipline-specific cognitive capabilities.

3. Previous PBL experiences emerged as a more powerful predictor of critical thinking gains (r = .34) compared to prior academic performance (r = .21), emphasizing the importance of repeated exposure to problem-based learning methodologies.
The qualitative findings complemented the quantitative results, revealing four primary mechanisms of critical thinking development: perspective transformation, metacognitive awareness, collaborative reasoning, and applied problem-solving confidence.
Practical implications are profound. The research suggests that PBL can be an effective strategy for cognitive skill enhancement across diverse academic domains, with multiple exposures progressively improving critical thinking capabilities.
Limitations notwithstanding, this study provides valuable insights for educators and institutions. It demonstrates that critical thinking is not an innate, fixed capacity but a skill that can be deliberately cultivated through intentionally designed, collaborative, and problem-oriented learning experiences.
As higher education continues to prioritize critical thinking as a crucial graduate capability, this research offers actionable evidence to inform pedagogical strategies, curriculum design, and faculty development initiatives.

REFERENCES

Adams, M. H., Whitlow, J. F., Stover, L. M., & Johnson, K. W. (1996). Critical Thinking as an Educational Outcome. *Nurse Educator*, *21*(3), 23–32.

Arthi, M. P., & Gandhimathi, S. N. S. (2024). *The criticality of critical thinking skills in higher education* (pp. 94–100). https://doi.org/10.58532/v3bgso4p4ch2

Asri, I. H., Jampel, N., Bagus, I., Arnyana, P., Suastra, W., & Nitiasih, P. K. (2024). Profile of Problem Based Learning (PBL) Model in Improving Students' Problem Solving and Critical Thinking Ability. *KnE Social Sciences*. https://doi.org/10.18502/kss.v9i2.14898

Astri, E. K., Siburian, J., & Hariyadi, B. (2022). Pengaruh Model Project Based Learning terhadap Keterampilan Berpikir Kritis dan Berkomunikasi Peserta Didik. *Biodik: Jurnal Ilmiah Pendidikan Biologi*, *8*(1), 51–59. https://doi.org/10.22437/bio.v8i1.16061

Damme, D. Van, Zahner, D., Cortellini, O., Dawber, T., & Rotholz, K. (2023). Assessing and developing critical-thinking skills in higher education. *European Journal of Education*. https://doi.org/10.1111/ejed.12563

Desai, M. S., Berger, B. D., & Higgs, R. (2016). Critical Thinking Skills for Business School Graduates as Demanded by Employers: A Strategic Perspective and Recommendations. *The Academy of Educational Leadership Journal*, *20*(1), 10. https://www.questia.com/library/journal/1P4-2123020027/critical-thinking-skills-for-business-school-graduates

Dilekli, Y. (2020). *Project-Based Learning* (pp. 53–68). IGI Global. https://doi.org/10.4018/978-1-7998-3146-4.CH004

Eswaran, U. (2024). *Project-Based Learning* (pp.

23–43). IGI Global. https://doi.org/10.4018/979-8-3693-2169-0.ch002

Franco, A. H., Vieira, R. M., & Tenreiro-Vieira, C. (2018). Educating for critical thinking in university: The criticality of critical thinking in education and everyday life. *Essachess : Journal for Communication Studies*, *11*(2), 131–144. http://www.essachess.com/index.php/jcs/article/download/429/463

Hasiana, I., Aisyah, A., Mudhar, M., Hartanti, J., & Mufidah, E. F. (2024). Efektivitas Model Pembelajaran Berbasis Project (PBL) untuk Meningkatkan Kemampuan Berpikir Kritis Reflektif pada Mahasiswa. *Utile: Jurnal Kependidikan*, *10*(2), 53–62. https://doi.org/10.37150/jut.v10i2.3140

Huang, F. (n.d.). *The Role of Critical Thinking in Higher Education*. https://doi.org/10.3969/j.issn.1008-4681.2006.01.045

Insyasiska, D., Zubaidah, S., & Susilo, H. (2015). *Pengaruh Project Based Learning Terhadap Motivasi Belajar, Kreativitas, Kemampuan Berpikir Kritis, Dan Kemampuan Kognitif Siswa Pada Pembelajaran Biologi*. *7*(1), 118842. https://doi.org/10.17977/JPB.V7I1.713

King, P. M., Wood, P. K., & Mines, R. A. (1990). Critical Thinking among College and Graduate Students. *The Review of Higher Education*, *13*(2), 167–186. https://doi.org/10.1353/RHE.1990.0026

Kokotsaki, D., Menzies, V., & Wiggins, A. (2016). Project-based learning: A review of the literature. *Improving Schools*, *19*(3), 267–277. https://doi.org/10.1177/1365480216659733

Lau, J. Y. F. (2024). Revisiting the origin of critical thinking. *Educational Philosophy and Theory*. https://doi.org/10.1080/00131857.2024.2320199

Lee, C. S., & Chou, C.-C. (2018). Discipline-Specific Critical Thinking Curriculum with A Problem Solving Life Cycle Framework. *International Conference on Computational Science*. https://doi.org/10.1109/CSCI46756.2018.00135

Marasri, S. (2019). *Developing Critical Thinking Skills in the 21st Century*. *3*(2), 105–122. http://www.ojs.mcu.ac.th/index.php/mcu-nan/article/download/4503/3282

Marzuki, M., & Basariah, B. (2017). *The Influence of Problem-Based Learning and Project Citizen Model in The Civic Education Learning on Student's Critical Thinking Ability and Self Discipline*. *36*(3), 196203. https://doi.org/10.21831/CP.V36I3.14675

Moustafa, A., & Al-Rashaida, M. (2024). *Fostering Students' Critical Thinking Through the Implementation of Project-Based Learning* (pp. 42–53). IGI Global. https://doi.org/10.4018/979-8-3693-0880-6.ch004

Raj, T., Chauhan, P., Mehrotra, R., & Sharma, M. (2022). Importance of Critical Thinking in the Education. *World Journal of English Language*, *12*(3), 126. https://doi.org/10.5430/wjel.v12n3p126

Rivas, S. F., Saiz, C., & Almeida, L. S. (2023). The Role of Critical Thinking in Predicting and Improving Academic Performance. *Sustainability*, *15*(2), 1527. https://doi.org/10.3390/su15021527

Ruano-Borbalan, J. (2023). Understanding and fostering the development of critical thinking education and competences. *European Journal of Education*, *58*(3), 347–353. https://doi.org/10.1111/ejed.12572

Sutrisno, D., & Abbas, A. (2023). Fostering Critical Thinking through Integrating Edpuzzle in Blended Learning. *Global Synthesis in Education Journal*. https://gse-journal.net/index.php/gse/article/view/12

Sutrisno, D., Abidin, N. A. Z., Pambudi, N., & ... (2023). EXPLORING THE BENEFITS OF MULTIMODAL LITERACY IN ENGLISH TEACHING: ENGAGING STUDENTS THROUGH VISUAL, AUDITORY, AND DIGITAL …. *Global Synthesis in …*. https://gse-journal.net/index.php/gse/article/view/16

Vincent-Lancrin, S. (2024). *Critical thinking* (pp. 124–128). Edward Elgar Publishing. https://doi.org/10.4337/9781035317967.ch27

Yousuf, A., Mustafa, M., & Cruz, A. D. La. (n.d.). *Project Based Learning*. https://doi.org/10.18260/1-2--16081

Zhang, Y. (2012). Critical Thinking as an Educational Ideal. *The Journal of Higher Education*. https://en.cnki.com.cn/Article_en/CJFDTOTAL-HIGH201211012.htm

ZHENG, X., & LI, R. (n.d.). *Cultivating Critical Thinking: an Important Dimension for College Education*. https://doi.org/10.3969/j.issn.1001-5035.2010.05.019