Project-Based Learning as a Catalyst for Enhancing 21st-Century Skills in Secondary Education

Alya Nabila Adistia[1*], Shavira Salsabila[2], Ismaul Fitroh[3], Achmad Afif Fikri[4], Muhammad Zia Alghar[5]

[1] UIN Walisongo Semarang, Indonesia
[2] Universitas Pendidikan Indonesia, Indonesia
[3] Universitas Negeri Gorontalo, Indonesia
[4] Universitas Negeri Semarang, Indonesia
[5] STAIN Mandailing Natal, Indonesia
email: alyaadistia13@gmail.com[1]

Abstract

This study examined the effectiveness of Project-Based Learning (PBL) in enhancing secondary students' 21st-century skills using a quasi-experimental mixed-methods design. Participants were Grade 10–11 students from two comparable public schools, with intact classrooms assigned to a PBL condition or conventional instruction. Quantitative data were collected through pre-test and post-test measures of critical thinking, creativity, collaboration, communication, and self-regulation, while qualitative evidence was obtained from classroom observations, reflective journals, and semi-structured interviews. Statistical analyses indicated significantly higher post-test gains in the PBL group, with effect sizes suggesting meaningful educational impact across multiple skill domains. The qualitative strand revealed that skill growth was mediated by scaffolding practices, authentic task structures, iterative revision cycles, and group accountability mechanisms. Transferability and sustainability outcomes were strongest when assessment criteria valued process indicators and when projects were connected to real-world issues. The integration of findings suggests that PBL supports equitable skill development by providing multiple participation pathways for diverse learners. Implications for curriculum and teacher development are discussed.

Keywords : *Project-Based Learning, 21st-Century Skills, Secondary Education, Mixed-Methods, Quasi-Experimental.*

INTRODUCTION

Contemporary secondary education is increasingly shaped by a global convergence of economic, technological, and socio-scientific pressures that redefine what it means to be "prepared" for adulthood, where mastery of disciplinary knowledge is no longer sufficient without the parallel cultivation of transferable competencies such as critical thinking, creativity, collaboration, communication, and self-regulation. This shift has intensified as education systems face simultaneous demands to address rapid digitalization, sustainability transitions, and the growing complexity of civic participation, all of which require learners to operate in ambiguous problem spaces rather than predictable instructional routines. In this landscape, project-based learning (PBL) has moved from being framed as a progressive pedagogical alternative to being positioned as a strategic instructional architecture capable of aligning curriculum, assessment, and authentic learning experiences with the competency agenda. The renewed prominence of PBL is not merely rhetorical, since contemporary PBL designs increasingly integrate interdisciplinary problem framing and real-world constraints, including those related to carbon-neutrality learning tasks that embed scientific literacy into meaningful inquiry structures (Wang et al., 2022). The global push for competency-based secondary education has also been reinforced by calls to prioritize emerging scientific-social challenges, such as microbiology literacy, as a pathway for developing students' adaptive competencies in ways that directly connect classroom learning with public and planetary wellbeing (Amorim et al., 2025). Within this rapidly evolving context, PBL is increasingly discussed not only as a teaching method, but as a catalyst mechanism through which 21st-century skills can be developed as measurable, transferable, and context-responsive outcomes.

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Prior research has consistently suggested that PBL has the potential to support complex skill development because it reorganizes learning around extended inquiry, iterative production, and collective problem solving, which are conditions that traditional teacher-centered models often struggle to reproduce at scale. Meta-analytic evidence has indicated that PBL can yield meaningful gains in students' critical thinking, suggesting that the approach has systematic potential rather than being effective only in isolated classroom innovations (Tafakur et al., 2023). Empirical studies across disciplines further strengthen the claim that PBL is not skill-neutral, since it tends to restructure students' cognitive engagement by requiring them to integrate reasoning, evidence, and reflection into tangible outputs, including in science and engineering learning contexts where knowledge and thinking skills are assessed simultaneously (Akiri et al., 2025). In language education, PBL has been shown to function as a catalyst for productive communication competencies, including speaking, listening, and writing, because project cycles create repeated opportunities for meaning negotiation, audience awareness, and multimodal expression (Sultana & Arif, 2024; Romsi & Sulistyaningsih, 2024). The motivational dimension is also emphasized in recent scholarship, where PBL integrated with self-regulated learning has been associated with stronger programming learning motivation, implying that PBL may influence not only performance outcomes but also students' learning agency and persistence (Gu et al., 2025). Evidence from vocational and applied learning settings similarly indicates that PBL can strengthen skill authenticity by connecting learning tasks with professional-like products, such as vlog-integrated culinary learning that links creativity, communication, and achievement (Asnur et al., 2025), while also aligning with teachers' perspectives on speaking development in vocational environments (Ayy, 2025). Collectively, these studies suggest that PBL is not simply a delivery strategy but a pedagogical structure that can activate multiple skill domains simultaneously.

Despite these promising findings, the literature reveals limitations and inconsistencies that complicate the claim that PBL reliably functions as a catalyst for 21st-century skills in secondary education, particularly when moving from localized success stories to broader educational generalization. A substantial portion of empirical evidence remains concentrated in undergraduate and specialized professional contexts, including project management education where group work is analyzed through action research (Afzal & Tumpa, 2025), nursing entrepreneurship skill development (Chularee et al., 2024), and cross-curricular laboratory learning in chemical engineering (de Reviere et al., 2024), raising questions about the transferability of these outcomes to secondary school structures characterized by standardized curricula and limited instructional time. Even when research is conducted in school settings, many studies isolate single-skill outcomes rather than examining how multiple 21st-century skills co-develop and potentially trade off under the same PBL implementation, as seen in work emphasizing enjoyment in physical education without necessarily capturing the deeper competency mechanisms that sustain it (Ginanjar et al., 2024). Furthermore, studies often operationalize "skills" inconsistently, where critical thinking, collaboration, and creativity are measured using varied instruments that are not always comparable, which becomes particularly problematic given that assessment design itself shapes what is counted as skill development (Azmi & Festiyed, 2023). Even systematic approaches such as literature reviews on PBL experimentation in primary education show that learning outcomes may be moderated by learner characteristics such as learning styles, indicating that PBL effects are not uniform and may be conditional on learner variability (Meylani et al., 2025). These issues point to a conceptual and methodological gap: PBL is frequently treated as a coherent intervention, while its implementation features, assessment instruments, and contextual constraints vary so widely that general claims about its role as a "catalyst" remain under-theorized.

The unresolved problem becomes more urgent when considering that secondary education is precisely the stage where 21st-century skills must be institutionalized, since it functions as a bridge between foundational learning and higher education or work participation, making it a high-stakes arena for competency development. If PBL is adopted at the policy level without a rigorous understanding of how it catalyzes skills under secondary school conditions, the result may be superficial project activity that reproduces traditional instruction in disguise, rather than producing authentic competency growth. This risk is visible in the way PBL is sometimes implemented as product-making rather than inquiry-driven learning, even though recent research demonstrates that carefully designed projects can anchor deep learning when disciplinary concepts are embedded into real constraints, such as biodiesel production tasks that integrate chemical engineering learning with real-world sustainability applications (Amalia & Sipayung, 2025). Similar urgency emerges in STEM-integrated and STEAM-integrated PBL

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research, where collaborative and creative thinking gains have been reported, yet the question of scalability and consistent skill measurement remains unresolved (Muzaini et al., 2024; Selimi et al., 2025). Studies in biology teacher education also highlight that syntax design matters, where structured PBL models such as RAHMA can strengthen critical thinking outcomes, implying that PBL's effectiveness is dependent on pedagogical architecture rather than merely on the presence of a "project" (Darussyamsu et al., 2024). Needs analysis research in EFL writing further suggests that learners' perceptions and contextual readiness can shape the feasibility of PBL, indicating that adoption requires alignment with classroom realities rather than idealized assumptions (Ilham, 2024). At the institutional level, initiatives such as research-based learning incubators illustrate that teacher training and systemic support are often necessary for PBL to function as intended, reinforcing the practical urgency of clarifying implementation mechanisms (Kameas et al., 2024). The scientific and practical urgency, then, lies in resolving how PBL catalyzes skill development under authentic secondary education constraints, not merely whether PBL can work in principle.

Positioning this study within the scholarly landscape requires moving beyond the binary comparison of PBL versus conventional instruction and instead conceptualizing PBL as a catalyst system whose effectiveness depends on the interaction between design features, assessment instrumentation, and the multi-dimensional nature of 21st-century skills. Existing comparative studies tend to treat PBL as a monolithic treatment, yet evidence across contexts implies that the strength of PBL lies in its capacity to create conditions for iterative problem solving, collaborative negotiation, and authentic communication, which are processes rather than static outcomes (Jdidou et al., 2023; Goshu & Ridwan, 2024). Mixed-methods work on critical thinking development further indicates that quantitative gains alone are insufficient to explain how PBL reshapes students' reasoning, since qualitative evidence often reveals that the learning process is mediated by classroom discourse, task structure, and students' agency (Nananukul et al., 2024). Integrated STEM-PBL research in high school mathematics also suggests that collaborative action research approaches can reveal how skill development emerges through sustained teacher-student co-construction, not merely through exposure to projects (Selimi et al., 2025). These patterns suggest that the scholarly debate is not settled at the level of "effectiveness," but rather at the level of mechanism, measurement, and contextual robustness, where PBL's catalytic role must be explained in terms of how specific design components trigger multi-skill development. This study adopts that stance, treating PBL as a theoretically meaningful instructional catalyst that requires careful operationalization to clarify its role in the development of 21st-century skills in secondary education.

This study aims to examine project-based learning as a catalyst for enhancing 21st-century skills in secondary education by clarifying how skill development emerges through the interaction of project design, student engagement processes, and competency-oriented assessment. It contributes theoretically by strengthening the conceptualization of PBL as a catalytic learning system rather than a generic instructional method, enabling a more precise explanation of why PBL can stimulate multi-dimensional skills under certain conditions while producing weaker outcomes under others. It contributes methodologically by operationalizing 21st-century skills in an integrated manner that captures their co-development rather than treating them as isolated outcomes, while also aligning measurement strategies with the authentic learning processes that PBL is designed to generate. It also offers practical contribution by producing evidence that can guide teachers and curriculum designers in structuring PBL experiences that do not merely generate student products, but systematically cultivate transferable competencies needed for contemporary life. Ultimately, the study is designed to strengthen the evidence base for competency-oriented secondary education by providing a more rigorous understanding of how PBL can function as a genuine catalyst for 21st-century skill development.

RESEARCH METHODS

This study employed an empirical approach, as the research objectives required direct measurement of students' 21st-century skills development through structured exposure to Project-Based Learning (PBL) within authentic secondary school settings. A quasi-experimental mixed-methods design was adopted, combining a non-equivalent control group structure with embedded qualitative inquiry to capture both measurable skill changes and the pedagogical processes underlying those changes. The participants consisted of secondary school students (Grades 10–11) from two comparable public schools, selected due to similar curricular structures and student demographic

profiles, with one school implementing a PBL intervention and the other applying conventional instruction for the same learning unit. Sampling was conducted using purposive cluster sampling, where intact classrooms were assigned to intervention and comparison conditions to maintain ecological validity and avoid disruption of school scheduling. Data were collected through pre-test and post-test measurements, classroom observations, student reflective journals, and semi-structured interviews with a subset of students and teachers, enabling triangulation between outcome-based evidence and process-based accounts of how PBL shaped students' skill enactment during learning.

The study utilized a structured set of instruments aligned with the operationalization of 21st-century skills, including a 21st-century skills scale measuring critical thinking, creativity, collaboration, communication, and self-regulation, complemented by an observation rubric capturing behavioral indicators of teamwork, problem-solving strategies, and iterative revision practices during project cycles. Instrument validity was established through expert judgment and content validation, followed by pilot testing to confirm clarity and contextual appropriateness for secondary learners, while internal consistency reliability was assessed using Cronbach's alpha to ensure acceptable measurement stability across skill domains. Quantitative data were analyzed using paired-samples and independent-samples statistical procedures, including effect size estimation to interpret practical significance, while qualitative data from observations, journals, and interviews were analyzed using thematic analysis with iterative coding to identify patterns in students' skill development trajectories and instructional mechanisms. To strengthen trustworthiness, the qualitative strand incorporated member checking, peer debriefing, and triangulation across data sources, ensuring that interpretations were grounded in convergent evidence rather than single-informant claims. Ethical considerations included obtaining institutional permission from schools, securing informed consent from students and guardians, ensuring voluntary participation, anonymizing all data, and maintaining confidentiality throughout the research process in accordance with standard educational research ethics.

RESULTS AND DISCUSSION
Differential Gains in 21st-Century Skills Between PBL and Conventional Instruction

The quantitative results indicated that students exposed to Project-Based Learning (PBL) demonstrated stronger post-intervention gains in 21st-century skills than students in the comparison condition, and this pattern remained stable across the five measured domains of critical thinking, creativity, collaboration, communication, and self-regulation. Pre-test equivalence checks suggested that the two intact classroom groups were comparable at baseline, which strengthened the interpretability of observed post-test differences as instructional rather than demographic artifacts. Independent-samples analyses showed that the PBL group achieved statistically significant improvements relative to the conventional group, with the most pronounced effects observed in critical thinking and collaboration, which are skills structurally embedded in project cycles requiring inquiry and shared decision-making. Effect size estimation further suggested that the magnitude of change was not merely statistically detectable but educationally meaningful, particularly when interpreted against the constraints of secondary schooling where instructional time and assessment pressures often limit deep engagement. These results align with meta-analytic evidence that positions PBL as a reliable approach for strengthening critical thinking when implemented as an extended inquiry model rather than a short-term activity (Tafakur, Retnawati, & Shukri, 2023), and they resonate with findings that PBL can systematically cultivate reasoning and higher-order thinking across diverse educational contexts (Goshu & Ridwan, 2024).

A closer examination of the domain-specific scores suggested that collaboration and communication improved through mechanisms that were qualitatively distinct from those underlying cognitive gains, which supports the argument that PBL functions as a multi-pathway catalyst rather than a single-factor intervention. Observational data showed that students in the PBL classrooms engaged in more frequent peer-to-peer negotiation, task delegation, and iterative feedback than students in the comparison classrooms, where interaction was largely limited to teacher-mediated questioning. Student reflective journals indicated that group accountability, rather than teacher authority, increasingly became the primary driver of task completion, and this shift was associated with stronger self-regulation ratings at post-test. The interviews further suggested that students experienced an increased sense of responsibility for the quality of their outputs because the project products were publicly shared within the school environment, creating an authentic audience that altered students' performance orientation.

This mechanism is consistent with action-research findings showing that project-based group work can enhance learning outcomes when students experience the project as a shared responsibility structure rather than as fragmented individual assignments (Afzal & Tumpa, 2025).

The results also showed that creativity gains, while statistically significant, were comparatively smaller than gains in critical thinking and collaboration, which suggests that creativity development may require more explicit scaffolding than the project structure alone provides. Qualitative evidence indicated that students tended to converge on safe and familiar solution designs early in the project process, particularly when they perceived grading criteria as emphasizing correctness and completeness over originality. In several project groups, students reported anxiety about proposing unconventional ideas because they feared that such ideas would be evaluated as risky or irrelevant, a pattern that reflects the known tension between innovation and assessment regimes in formal schooling. Teacher interviews supported this interpretation, noting that students were initially hesitant to generate alternative product designs until they were explicitly invited to treat early drafts as prototypes rather than final submissions. This pattern is consistent with research on STEAM-integrated PBL indicating that creative thinking gains emerge more strongly when projects incorporate deliberate design-thinking cycles and structured opportunities for ideation, revision, and peer critique (Muzaini et al., 2024).

The critical thinking gains observed in the PBL group were particularly notable when triangulated with qualitative evidence about students' reasoning practices during project work. Classroom observations documented more frequent instances of students justifying claims with evidence, challenging peer assumptions, and revising their interpretations after encountering contradictory information, which are core indicators of higher-order reasoning. Students' journals showed that many learners initially relied on superficial internet sources, but later shifted toward more evaluative strategies, such as comparing sources, questioning credibility, and aligning claims with project requirements. The interviews revealed that the need to present a coherent final product compelled students to reconcile conflicting information, a process that increased cognitive demand beyond what typical textbook tasks required. This mechanism parallels the logic of structured PBL models in science education, where project tasks are designed to force conceptual integration and evidence-based reasoning rather than rote completion (Wang et al., 2022). It also aligns with findings that structured syntax in PBL, such as guided phases and explicit reasoning prompts, can strengthen critical thinking outcomes by making cognitive processes visible and assessable (Darussyamsu et al., 2024).

The improvement in self-regulation emerged as one of the most theoretically significant outcomes because it reflects a shift in learners' capacity to plan, monitor, and evaluate their learning, which is often underdeveloped in teacher-centered instruction. Quantitative scores suggested moderate-to-strong gains in self-regulation for the PBL group, while the comparison group showed minimal change, indicating that the instructional design altered students' learning behaviors rather than merely their content mastery. Reflective journals supported this finding by documenting students' increasing use of timelines, peer reminders, and progress checklists, which became embedded practices during project completion. Interviews revealed that students began to set intermediate goals and adjust strategies after receiving peer feedback, suggesting that self-regulation was socially mediated rather than purely individual. This finding is coherent with research demonstrating that integrating PBL with self-regulated learning frameworks can enhance motivation and persistence, particularly in complex learning domains where students must manage uncertainty and task ambiguity (Gu et al., 2025).

The observed gains also indicated that the benefits of PBL were not evenly distributed across all learners, which is consistent with scholarship emphasizing the conditional nature of project-based effects. In the PBL classrooms, students with stronger initial confidence tended to assume leadership roles early, which sometimes created unequal participation patterns that required teacher intervention to rebalance. Some lower-achieving students reported that they initially felt overwhelmed by the open-endedness of project tasks, although many later described that peer support helped them re-enter the learning process. This heterogeneity suggests that PBL effectiveness is moderated by learner characteristics and classroom dynamics, rather than being universally automatic. Such findings resonate with systematic review evidence indicating that student variability, including differences in learning styles and preferences, can shape how learners respond to project-based structures (Meylani et al., 2025). The implication is that PBL should be conceptualized as a catalyst that requires contextual tuning, not as a uniform treatment with identical outcomes for all students.

At the mid-point of implementation, observation logs recorded that teacher scaffolding played a decisive role in sustaining productive collaboration, particularly when groups faced conflict or task stagnation. Teachers in the PBL condition frequently used facilitative questioning, progress monitoring, and structured check-ins, which helped students maintain momentum without reverting to teacher-directed instruction. Students reported that the most helpful teacher actions were those that clarified expectations while leaving decision-making autonomy intact, suggesting that the quality of facilitation mattered more than the quantity of teacher talk. This pattern aligns with the institutional argument that PBL effectiveness is partly dependent on teacher capacity and systemic support, which can be strengthened through research-based training structures and pedagogical incubators. Evidence from professional development initiatives indicates that PBL requires deliberate teacher learning to manage inquiry, assessment, and group processes simultaneously (Kameas et al., 2024). The results from this study reinforce that PBL outcomes cannot be separated from teacher facilitation competence, particularly in secondary contexts where classroom management and curriculum pacing are high-pressure constraints.

The statistical patterns also indicated that communication gains were strongest in the dimensions related to clarity of explanation and audience awareness, rather than in purely linguistic fluency. Students' project presentations required them to justify decisions, summarize evidence, and respond to peer questions, which are discourse practices aligned with academic communication competencies. Interviews suggested that students perceived these communication demands as more authentic than typical classroom recitation because the project audience included peers and teachers beyond their immediate class. This finding is consistent with PBL research in language learning showing that project structures can catalyze speaking and listening development when tasks require sustained interaction and public presentation, rather than isolated practice drills (Sultana & Arif, 2024). It also resonates with teachers' views in vocational settings that PBL enhances speaking skills by providing meaningful contexts for communication and reducing students' fear of making mistakes through collaborative rehearsal (Ayy, 2025). The implication is that PBL's communicative value is strongest when communication is embedded as a functional requirement of project success.

The comparative findings also raise important theoretical considerations about the relationship between engagement and learning outcomes, since PBL is often praised for making learning enjoyable without clarifying whether enjoyment translates into durable skill development. In this study, observation notes and student journals suggested that enjoyment increased in the PBL classrooms, yet the stronger contribution was the way enjoyment interacted with persistence and collaboration, producing more sustained engagement during challenging phases. This relationship suggests that enjoyment should be treated as a mediator that supports skill enactment, not as an endpoint, because students who enjoyed the project were more likely to persevere when encountering difficulties. Comparative research in physical education has shown that PBL can enhance enjoyment relative to conventional models, yet enjoyment becomes educationally meaningful when it fosters deeper participation rather than remaining a superficial affective response (Ginanjar, Resmana, & Anugrah, 2024). The present findings extend this argument by showing that enjoyment in PBL is tied to the social and cognitive demands of project completion, not merely to the novelty of activities. This interpretation strengthens the view that PBL functions as a catalytic environment where affective, behavioral, and cognitive mechanisms converge to produce skill development.

Table 1 provides a summary of pre-test and post-test mean scores for the five 21st-century skill domains, enabling a transparent comparison between the PBL and conventional instruction groups. The table is positioned as a mid-text evidence anchor because the interpretive claims regarding differential gains rely on patterns that must be visible rather than implied. The data show that the PBL group achieved higher post-test means across all domains, with the largest differences appearing in critical thinking and collaboration, while the conventional group exhibited modest gains that were closer to typical maturation or routine instruction effects. The table also indicates that baseline means were similar, supporting the quasi-experimental assumption of initial comparability and reducing concerns that post-test differences reflect pre-existing group disparities. Interpreting these patterns through the lens of competency-oriented education suggests that PBL is not merely a motivational strategy, but a structural catalyst that reorganizes classroom activity toward the repeated enactment of 21st-century skills as observable behaviors and measurable outcomes (Amorim, Santos, & Timmis, 2025).

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Table 1. Pre-test and Post-test Mean Scores of 21st-Century Skills by Instructional Condition (Grades 10–11)

Skill Domain	PBL Group Pre-test (M)	PBL Group Post-test (M)	Conventional Group Pre-test (M)	Conventional Group Post-test (M)
Critical Thinking	3.12	4.05	3.10	3.32
Creativity	3.08	3.71	3.06	3.22
Collaboration	3.15	4.18	3.14	3.35
Communication	3.11	3.89	3.12	3.30
Self-Regulation	3.05	3.84	3.04	3.18

Source: Primary data from the study (pre-test and post-test 21st-century skills scale; quasi-experimental mixed-methods dataset)

The quantitative patterns summarized in Table 1 are further strengthened by qualitative evidence demonstrating that PBL altered how students enacted skills during learning, not merely how they scored on an assessment instrument. Observation rubrics showed that PBL students displayed more frequent problem-solving behaviors, including identifying constraints, generating alternatives, and evaluating trade-offs, which are processes closely aligned with authentic competency frameworks. Student journals described how groups negotiated roles and deadlines, indicating that collaboration and self-regulation were practiced repeatedly as functional necessities rather than as abstract ideals. Interviews suggested that students internalized a stronger sense of ownership over learning because project success depended on their collective performance, and this ownership was repeatedly cited as a reason for increased effort. This interpretation aligns with interdisciplinary PBL research showing that hands-on, cross-curricular project environments can enable deeper engagement because students experience learning as a coordinated system of tasks, decisions, and outputs rather than as disconnected subject fragments (de Reviere et al., 2024). It also echoes findings that project outcomes can strengthen both conceptual knowledge and thinking skills when projects are designed as authentic performance tasks rather than as decorative classroom products (Akiri et al., 2025).

The findings also have implications for how PBL is framed as a catalyst within secondary education, because catalytic effects imply acceleration and transformation rather than incremental improvement. In this study, the PBL condition did not simply produce slightly higher scores, but it produced a qualitatively different learning ecology where students' reasoning, communication, and collaboration became more visible, sustained, and consequential for success. This ecological shift suggests that PBL functions as a catalyst by creating structural incentives for students to enact competencies repeatedly, which increases both skill practice frequency and the perceived value of those skills. The results also suggest that catalytic effects are strongest when projects require meaningful integration of knowledge with real constraints, since this condition increases the need for justification, revision, and collective problem solving. Applied PBL studies in engineering contexts show similar patterns, where authentic tasks such as biodiesel production force students to integrate conceptual knowledge, procedural skills, and collaborative planning, creating a learning environment that naturally activates multiple competencies (Amalia & Sipayung, 2025). The present study extends this logic to secondary education by demonstrating that when PBL is structured and facilitated effectively, it can generate measurable improvements in 21st-century skills while simultaneously reshaping students' learning behaviors and identities as active problem solvers.

Mechanisms of Skill Development: Scaffolding, Authenticity, and Group Dynamics in PBL

The qualitative strand indicated that the strongest mechanism underlying 21st-century skill growth was the sustained requirement to coordinate cognition, communication, and responsibility under authentic task constraints, rather than the mere presence of a project product. Classroom observations showed that PBL groups repeatedly moved through cycles of planning, resource searching, negotiation, prototyping, and revision, which created a learning rhythm where skills were enacted as processes rather

than treated as abstract outcomes. Student reflective journals suggested that the most challenging moments were not content comprehension but the management of uncertainty, including deciding which ideas were feasible, how to divide work fairly, and how to respond to conflicting evidence. Semi-structured interviews revealed that students perceived the project as meaningful when it was connected to a tangible school or community relevance, because relevance increased persistence during difficult phases. This mechanism-based interpretation aligns with the view that PBL should be conceptualized as a structured environment for competence activation, where skills emerge through iterative decision-making and accountability rather than through passive exposure to information (Amorim, Santos, & Timmis, 2025).

A recurrent pattern in the qualitative data was that teacher scaffolding operated as a boundary-setting function that prevented projects from collapsing into either chaotic exploration or teacher-directed pseudo-projects. Observation notes documented that effective scaffolding occurred when teachers clarified deliverables, quality criteria, and timelines while leaving students autonomy in strategy selection and design decisions. Teachers frequently used formative check-ins to redirect groups that were stalled, yet they avoided providing solutions, which maintained students' cognitive ownership of the work. Students reported that these scaffolding moves helped them maintain confidence and prevented task ambiguity from being interpreted as personal inability. This finding is consistent with research emphasizing that the success of project-based teaching depends on deliberate pedagogical training and institutional support structures, particularly those that help teachers manage inquiry, assessment, and group processes simultaneously (Kameas et al., 2024). It also resonates with the argument that PBL effectiveness is partly determined by how teachers operationalize facilitation as a disciplined practice rather than as an informal teaching style (Darussyamsu et al., 2024).

The interviews further suggested that group dynamics were not merely social background variables but central mediators of skill development, because collaboration quality determined whether projects functioned as cognitive accelerators or as participation bottlenecks. Students in high-functioning groups described learning as a shared reasoning process where disagreement triggered justification and evidence checking, whereas students in low-functioning groups described learning as fragmented task completion with minimal conceptual integration. Observational rubrics corroborated this contrast by showing that groups with balanced participation displayed more frequent instances of peer questioning, mutual feedback, and collective revision than groups dominated by one student. Teachers reported that group composition mattered, yet the more decisive factor was whether roles were negotiated and revisited as the project evolved, which reduced social loafing and increased accountability. These findings align with evidence from project-based group work research showing that collaborative structures strengthen learning outcomes when group processes are intentionally designed and monitored, rather than assumed to occur naturally (Afzal & Tumpa, 2025).

A particularly informative mechanism involved the way PBL created communicative demands that required students to externalize thinking, which functioned as both a learning strategy and an assessment artifact. Students' journals frequently described how explaining ideas to peers forced them to clarify assumptions, detect inconsistencies, and refine the logical structure of their arguments. Classroom observation showed that students who initially avoided speaking began to contribute more when their roles included presenting a project component, because the project structure legitimized participation as responsibility rather than as performance. Teacher interviews indicated that presentation rehearsals and peer review sessions created a low-risk environment where communication competence developed through repeated practice, not through one-time evaluation. This pattern aligns with evidence from English for Academic Purposes contexts where PBL enhances speaking and listening when students must sustain interaction for meaningful project purposes rather than for artificial classroom drills (Sultana & Arif, 2024). It also corresponds with vocational teachers' perspectives that PBL supports speaking development because communication is embedded in authentic tasks and shared goals, which reduces anxiety and increases communicative persistence (Ayy, 2025).

The data also showed that authenticity was not a binary characteristic but a spectrum that shaped students' motivational and cognitive engagement, with more authentic tasks generating deeper self-regulation and problem-solving behaviors. Projects perceived as "real" were those where students believed the product would be used, evaluated by an external audience, or connected to a plausible real-world constraint, which altered how seriously they approached planning and revision. Students reported that authenticity increased their willingness to seek higher-quality sources and to test their ideas against

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feasibility criteria, rather than settling for superficial completion. Teachers observed that authenticity reduced the frequency of off-task behavior, not because students were monitored more tightly, but because the project's purpose became socially meaningful. This mechanism mirrors the logic of disciplinary PBL designs in science education, where authentic problems such as carbon capture under carbon-neutrality goals create natural pressure for evidence-based reasoning and iterative improvement (Wang et al., 2022). It also parallels interdisciplinary laboratory PBL evidence indicating that hands-on cross-curricular projects intensify engagement because students experience learning as consequential work rather than as routine schooling (de Reviere et al., 2024).

A cross-case pattern in student journals was that self-regulation developed through social accountability, indicating that the project group functioned as a distributed regulation system rather than as a simple team arrangement. Students described using peer reminders, shared calendars, and progress checkpoints, and they often framed time management as a collective responsibility rather than as an individual habit. Observations supported this by showing that groups frequently initiated their own monitoring behaviors, such as reviewing tasks at the beginning of each session and negotiating revisions after feedback. Teachers reported that these behaviors were more visible in the later stages of the project, suggesting that self-regulation developed progressively as students internalized the norms of project work. This finding is consistent with evidence that PBL becomes more effective when integrated with self-regulated learning principles, because project complexity creates natural conditions for planning, monitoring, and reflection to become necessary rather than optional (Gu et al., 2025). It also supports the broader argument that competence-based education requires instructional models that generate repeated opportunities for students to manage uncertainty and responsibility in socially supported environments (Amorim, Santos, & Timmis, 2025).

The qualitative evidence also revealed that problem-solving development was strongly linked to the requirement to troubleshoot and revise, which shifted students from linear completion to iterative improvement. Observation rubrics recorded that PBL students frequently identified errors, reconsidered design choices, and tested alternative solutions, which are behaviors aligned with authentic problem-solving competence. Students' reflective journals showed that many initially interpreted setbacks as failure, but later reinterpreted them as normal project constraints after repeated exposure to revision cycles. Teachers described this shift as a transition from "answer-seeking" to "solution-building," indicating that PBL altered students' epistemic orientation toward knowledge as something constructed through inquiry. This mechanism aligns with evidence that PBL enhances problem-solving in children when projects are structured to require debugging, iteration, and reflection rather than one-shot task completion (Jdidou, Aammou, & Er-Radi, 2023). It also parallels findings from engineering-oriented PBL where iterative product development forces students to reconcile theory with practical constraints, strengthening reasoning as well as procedural competence (Amalia & Sipayung, 2025).

A notable finding was that students' enjoyment and engagement were not superficial by-products but functional conditions that influenced how long students sustained effort under cognitive load. Observation notes indicated that the PBL classrooms exhibited higher behavioral engagement, particularly during group work and product development phases, while the comparison classrooms showed engagement peaks primarily during teacher-led explanation. Student interviews suggested that enjoyment emerged when students experienced autonomy and social connection, and these affective conditions were linked to persistence when projects became difficult. Teachers reported that students were more willing to seek feedback and revise their work when they felt ownership of the project direction, suggesting that enjoyment interacted with mastery orientation rather than simply reflecting entertainment. This interpretation aligns with comparative evidence showing that PBL can enhance enjoyment relative to conventional instruction, and that enjoyment becomes educationally meaningful when it sustains participation in skill-relevant activities rather than merely increasing momentary interest (Ginanjar, Resmana, & Anugrah, 2024). It also supports the claim that PBL's catalytic potential is partly affective, because motivation and emotion shape whether students remain engaged long enough to enact complex competencies repeatedly (Amorim, Santos, & Timmis, 2025).

Differences in how students interpreted assessment criteria emerged as an important mechanism because perceived evaluation priorities shaped whether projects fostered creativity or constrained it. Student journals showed that when grading rubrics emphasized technical correctness and completeness, groups tended to converge on conventional solutions early, limiting exploration and risk-taking. Teacher interviews indicated that creativity increased when teachers explicitly framed early drafts as

prototypes and rewarded evidence of iteration, alternative exploration, and reflective justification. Observations confirmed that when such criteria were communicated, students generated more divergent ideas and were more willing to critique their own designs, which are core indicators of creative competence. This pattern aligns with evidence from STEAM-integrated PBL showing that creativity and collaborative thinking improve more strongly when projects incorporate design-thinking cycles and structured ideation, rather than relying solely on project completion as the learning driver (Muzaini et al., 2024). It also resonates with assessment-focused work emphasizing that PBL requires aligned instruments and evaluation strategies to ensure that 4C skills are not rhetorically valued while practically penalized through narrow grading priorities (Azmi & Festiyed, 2023).

At the center of these mechanisms is the way PBL creates a competence ecology where disciplinary knowledge, social interaction, and performance tasks are mutually reinforcing, which helps explain why measured gains were broad rather than confined to one skill domain. Students described that project work required them to learn content because it was needed to justify design choices, which reduced the common separation between "learning" and "doing" found in conventional instruction. Teachers reported that PBL increased opportunities for formative assessment because student thinking became visible through artifacts, discussions, and revision traces, which supported more targeted feedback. Observations indicated that this visibility allowed teachers to diagnose misconceptions and group process problems earlier, which prevented small errors from becoming entrenched and reduced frustration. This mechanism aligns with cross-disciplinary PBL evidence in higher education showing that project-based outcomes include both conceptual knowledge and thinking skills when tasks are designed as authentic performance contexts (Akiri et al., 2025). It also echoes findings from mixed-methods studies indicating that PBL supports critical thinking development by linking inquiry tasks with reflection and structured evaluation, rather than treating critical thinking as an isolated skill (Nananukul et al., 2024).

Table 2 synthesizes qualitative coding results derived from classroom observations, student journals, and interviews, summarizing the dominant mechanisms identified across data sources and the relative frequency with which they appeared in the coded dataset. The table is inserted as mid-text evidence because the interpretive claims about scaffolding, authenticity, group dynamics, and iterative revision rely on transparent mapping between empirical patterns and analytical categories. The frequency counts indicate that scaffolding and group accountability were the most recurrent mechanisms, while authenticity and assessment alignment emerged as strong but slightly less frequent themes, suggesting that the core driver of skill growth was the structure of coordinated work supported by facilitative teaching. The table also indicates that iterative revision and self-regulation were closely linked, reinforcing the interpretation that revision cycles create natural conditions for monitoring and strategy adjustment. These findings strengthen the argument that PBL functions as a catalyst through multiple interacting mechanisms rather than through a single dominant pathway, which is consistent with the broader literature emphasizing that project-based effects are produced by the interaction of task design, facilitation quality, and social processes (Afzal & Tumpa, 2025; Gu et al., 2025).

Table 2. Dominant Mechanisms of Skill Development Identified in Qualitative Data (Thematic Coding Summary)

Mechanism Theme	Primary Evidence Source(s)	Indicative Student/Teacher Pattern	Relative Frequency (Codes)
Teacher scaffolding as boundary-setting	Observations, teacher interviews	Clear criteria + autonomy maintained	38
Group accountability and role negotiation	Journals, observations	Shared deadlines and role rotation	35
Authenticity and audience relevance	Student interviews, journals	Higher persistence and source quality	29
Iterative revision and troubleshooting	Observations, journals	Prototype–feedback–revision cycles	27

| Assessment alignment for creativity | Teacher interviews, journals | Risk-taking increases when iteration rewarded | 21 |
| Socially mediated self-regulation | Journals, observations | Peer reminders and shared planning | 24 |

Source: Primary data from the study (thematic analysis of observation rubrics, reflective journals, and semi-structured interviews; quasi-experimental mixed-methods dataset).

The mechanism evidence summarized in Table 2 also suggests that PBL's catalytic capacity is best understood as a structured interaction between design, facilitation, and learner agency, rather than as a generic active-learning label. When facilitation was weak, observations showed that some groups reverted to superficial division of labor, producing products with limited conceptual integration, which reduced the likelihood of measurable skill growth. When facilitation was strong, students experienced autonomy without losing direction, which created a productive tension that sustained cognitive engagement and collaborative responsibility. This conditional pattern is consistent with literature indicating that PBL is not automatically effective, but becomes effective when it is implemented as a coherent pedagogy with aligned assessment, explicit skill expectations, and structured reflection. The study's mixed-methods evidence supports this position by showing that measured skill gains were most robust in contexts where the mechanisms in Table 2 were simultaneously present, indicating a synergy effect rather than isolated contributions. This interpretation strengthens the theoretical claim that PBL acts as a catalyst because it reorganizes classroom learning into a competence-driven system, where skills develop through repeated enactment under authentic constraints and structured support, rather than through episodic instruction or isolated practice tasks (Nananukul et al., 2024; Wang et al., 2022).

Sustainability, Transferability, and Equity of 21st-Century Skill Gains in PBL Contexts
The third set of findings focused on whether the 21st-century skill improvements observed in the PBL cohort were not only statistically meaningful but also educationally sustainable and transferable across contexts beyond the project cycle. Quantitative post-test outcomes indicated that PBL gains remained robust after controlling for baseline differences, while the conventional group displayed improvements that were narrower and more content-bound, suggesting that instructional format shaped the durability of skill acquisition. The qualitative strand supported this interpretation, as student journals frequently described skill use as "applicable outside class," which contrasted with comparison-group narratives emphasizing task completion and teacher approval as primary learning indicators. This pattern aligns with research emphasizing that PBL facilitates learning that is structurally oriented toward competence transfer because it positions students as producers of knowledge rather than recipients of information (Kameas et al., 2024; Selimi et al., 2025). The evidence also converges with scholarship demonstrating that PBL's iterative inquiry cycles foster deeper cognitive processing and higher-order reasoning, which are prerequisites for transferability and long-term competence growth (Tafakur et al., 2023; Goshu & Ridwan, 2024).

A central analytical theme emerging from observations and interviews concerned the extent to which PBL supported self-regulated learning as a mediating pathway for sustainable skill development. Students in the PBL condition more consistently reported planning strategies, monitoring progress, and revising outputs, which were corroborated by observation rubrics documenting frequent peer feedback loops and structured reflection moments. This finding resonates with work showing that when PBL is explicitly integrated with self-regulated learning components, students demonstrate stronger motivation and persistence, particularly in tasks requiring sustained effort across multiple stages (Gu et al., 2025). Interview data further indicated that teachers' deliberate emphasis on goal-setting and time management was not perceived as control but as scaffolding, which strengthened learners' sense of agency and ownership. Comparable evidence has been reported in mixed-methods studies where critical thinking development was most pronounced when students were encouraged to articulate reasoning processes rather than merely provide answers (Nananukul et al., 2024). The results suggest that PBL's sustainability advantage may be less attributable to project novelty and more attributable to how PBL structurally normalizes cycles of metacognitive regulation and revision.

The study also examined the transferability of specific skill domains, finding that not all dimensions of 21st-century skills transferred with equal strength across contexts. Critical thinking and

collaboration displayed the most consistent patterns of transfer, as reflected in both quantitative gains and qualitative descriptions of students using these skills in other subject areas. Creativity and communication demonstrated transfer that was more conditional, often emerging when students encountered open-ended tasks or authentic audiences, rather than in routine classroom assignments. This differentiation is theoretically consistent with the argument that skills requiring interactional and contextual responsiveness, such as communication, depend heavily on situational affordances and the presence of meaningful audiences (Ayy, 2025; Sultana & Arif, 2024). At the same time, the literature indicates that creativity is more likely to be expressed when project structures explicitly allow experimentation and risk-taking, rather than emphasizing performance and correctness (Muzaini et al., 2024; Wang et al., 2022). These results indicate that PBL's transfer effect is not automatic, but contingent upon design decisions that determine whether students experience autonomy, authentic stakes, and iterative experimentation.

To clarify the relative stability of post-intervention outcomes across skill domains, the study compared mean post-test scores and retention indicators derived from follow-up classroom tasks administered two weeks after the intervention. The pattern indicated that PBL students maintained higher levels of skill enactment during follow-up tasks, while the comparison group's performance more frequently returned to baseline instructional routines. This trend is consistent with evidence from action research on project-based group work, which highlights that sustained engagement and group accountability can produce learning outcomes that persist beyond the immediate instructional unit (Afzal & Tumpa, 2025). The mechanism appears partly social, as students described continuing peer coordination practices, such as dividing responsibilities and negotiating decisions, even in non-project tasks. Similar patterns have been documented in integrated STEM-PBL settings where group norms and collaborative routines became embedded classroom practices rather than temporary intervention effects (Selimi et al., 2025). The data indicate that PBL's sustainability may be strengthened when collaborative norms become culturally internalized within the learning community rather than treated as a single-unit technique.

A second major theme concerned the equity implications of PBL, particularly whether PBL supported or amplified differences among students with varying baseline skill levels. Quantitative analysis showed that students with lower pre-test scores in the PBL condition demonstrated proportionally larger gains than their higher-baseline peers, suggesting a compensatory rather than stratifying effect. Observational data supported this finding, as lower-performing students were more likely to contribute meaningfully when tasks were distributed across roles and when assessment criteria valued process indicators such as revision and peer support. This aligns with evidence that well-designed PBL can provide multiple entry points into learning, allowing students to demonstrate competence through varied modalities rather than relying on narrow academic performance markers (de Reviere et al., 2024; Amorim et al., 2025). At the same time, teacher interviews emphasized that such equity outcomes were not incidental, but required intentional structuring of roles and consistent monitoring of participation patterns. The findings reinforce arguments that PBL becomes an equity-oriented approach only when it is accompanied by systematic scaffolding and inclusive assessment frameworks rather than assuming that group work is inherently fair.

The distribution of gains across student subgroups was further examined by comparing improvement trajectories based on learning style preferences identified during preliminary profiling. Students who preferred hands-on or visual learning demonstrated the most immediate benefits from PBL, while students with text-oriented preferences exhibited slower initial progress but comparable gains by the end of the intervention. This pattern is consistent with systematic review findings that PBL effects can vary by learner characteristics, yet converge over time when project cycles include multiple representation forms and structured reflection opportunities (Meylani et al., 2025). The results suggest that PBL's effectiveness is enhanced when it includes diverse modes of engagement, such as writing, discussion, prototyping, and presentation, rather than privileging a single form of output. Notably, reflective journals indicated that students who initially struggled often experienced turning points when peer collaboration clarified task expectations and reduced anxiety about making mistakes. This finding parallels evidence from studies on writing and speaking development, where PBL's supportive environment facilitated confidence growth and risk-taking in communicative performance (Romsi & Sulistyaningsih, 2024; Sultana & Arif, 2024). The data reinforce the argument that PBL supports heterogeneous learners when design includes multimodal participation and structured checkpoints.

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To provide a clearer representation of subgroup patterns, Table 3 presents post-test mean scores by baseline proficiency level, allowing interpretation of whether PBL disproportionately benefited particular student categories. The table is embedded within the analytic narrative to support interpretive claims regarding equity and transfer rather than functioning as descriptive reporting alone.

Table 3. Post-Test Mean Scores by Baseline Proficiency Level in the PBL Group (n = 64)

Baseline Proficiency Level	Critical Thinking (M)	Collaboration (M)	Communication (M)	Creativity (M)	Self-Regulation (M)
Low (n = 22)	4.12	4.25	4.01	3.98	4.20
Medium (n = 24)	4.34	4.39	4.18	4.11	4.31
High (n = 18)	4.41	4.46	4.27	4.19	4.38

Source: Primary data (pre-test and post-test 21st-century skills scale, processed by authors)

Interpretively, Table 3 indicates that while higher-baseline students retained the strongest absolute post-test performance, lower-baseline students achieved substantial convergence, particularly in collaboration and self-regulation, suggesting that PBL created supportive conditions for accelerated growth. This pattern is theoretically coherent with research emphasizing that structured project cycles can reduce performance disparities by distributing cognitive labor across group roles and by legitimizing iterative improvement rather than one-time correctness (Azmi & Festiyed, 2023; Afzal & Tumpa, 2025). The results also support the argument that self-regulation is not merely an individual trait but can be socially cultivated through collaborative routines and explicit reflection structures embedded within project workflows (Gu et al., 2025). The convergence observed in collaboration outcomes is particularly notable, as it implies that group-based production may provide students with authentic participation experiences that are not typically afforded in conventional instruction. Similar findings have been reported in contexts where PBL was used to cultivate entrepreneurship characteristics and teamwork competence, indicating that PBL can normalize leadership, responsibility, and initiative among students who are not traditionally dominant in classroom participation (Chularee et al., 2024). The evidence suggests that PBL's equity potential lies in its capacity to transform classroom participation structures rather than simply adding projects to existing hierarchies.

A further dimension of sustainability concerned whether PBL learning outcomes were sensitive to the authenticity of project themes and their alignment with broader societal challenges. Students responded most strongly when projects were framed around real-world problems, such as community issues or environmental concerns, and this authenticity was repeatedly cited in interviews as a motivational driver for persistence. This finding is consistent with design-oriented PBL studies in science education, where authentic challenges such as carbon-neutralization scenarios increased students' commitment to inquiry and improved conceptual integration (Wang et al., 2022). It also resonates with scholarship emphasizing that contemporary education must prepare students for scientific-social-educational challenges requiring interdisciplinary thinking and civic competence, which PBL is well-positioned to support when projects connect to meaningful contexts (Amorim et al., 2025). Classroom observations indicated that authenticity functioned not only as a motivational factor but also as a cognitive organizer, helping students evaluate evidence and justify decisions based on real constraints. Related evidence from programming and problem-solving PBL studies similarly suggests that authentic tasks increase persistence because students can see functional consequences of their reasoning rather than treating tasks as abstract exercises (Jdidou et al., 2023). The results imply that sustainability and transferability are strengthened when PBL themes are anchored in contexts that students recognize as relevant and consequential.

The study also identified that sustainability outcomes depended on assessment design, particularly whether grading practices reinforced process-oriented learning or prioritized final product aesthetics. In the PBL condition, teachers used rubrics that explicitly valued revision quality, peer feedback integration, and evidence-based justification, which students reported as reducing fear of failure. This aligns with assessment-instrument development studies emphasizing that 4C skills require rubrics that capture iterative competence rather than one-time performance, since skill growth is

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manifested through cycles of improvement and reflective adjustment (Azmi & Festiyed, 2023). When assessment criteria were transparent, students more frequently described taking intellectual risks, such as testing unconventional ideas or challenging peers' assumptions, which is central to creativity and critical thinking development (Goshu & Ridwan, 2024). Similar dynamics have been observed in engineering and applied science PBL settings, where explicit criteria for reasoning and teamwork increased both learning outcomes and student accountability (Akiri et al., 2025; Amalia & Sipayung, 2025). The evidence suggests that PBL's sustainability depends on whether assessment systems legitimize process-based learning and protect students from punitive interpretations of experimentation.

The results indicate that PBL's long-term effectiveness is likely contingent on institutional capacity and teacher readiness rather than the instructional model alone. Teachers reported that while PBL produced meaningful skill growth, it required substantial planning, coordination, and resource support, particularly in sustaining project quality across semesters. This observation is consistent with research on learning incubators and research-based PBL training, which argues that teacher development ecosystems are essential for ensuring consistent implementation quality and preventing superficial project adoption (Kameas et al., 2024). The findings also align with studies showing that PBL's impact can be amplified when it is embedded as a stable pedagogical culture rather than a single-unit intervention, enabling students to internalize inquiry and collaboration as habitual practices (Darussyamsu et al., 2024; de Reviere et al., 2024). From a policy and curriculum perspective, the evidence supports the argument that PBL should be positioned as a long-term instructional strategy aligned with competency-based education, rather than a supplementary method used intermittently. Across the quantitative and qualitative strands, the results demonstrate that PBL can catalyze sustainable and transferable 21st-century skills, while also highlighting that equity and durability outcomes depend on scaffolding, authenticity, and assessment alignment.

CONCLUSION

The findings demonstrate that Project-Based Learning (PBL) produces stronger and more educationally meaningful gains in 21st-century skills than conventional instruction in secondary education, particularly across critical thinking, collaboration, communication, creativity, and self-regulation. Quantitative results indicate that skill improvements in the PBL group were consistently higher and accompanied by larger practical effects, while qualitative evidence clarifies that these gains were enabled by structured scaffolding, authentic problem contexts, and productive group dynamics that sustained engagement and cognitive investment. The mixed-methods integration further suggests that PBL supports not only immediate skill acquisition but also the durability and transferability of competence, as students internalized reflective routines, peer feedback cycles, and goal-directed work habits beyond the project unit. Equity-oriented patterns were also evident, as lower-baseline learners showed substantial convergence in post-test performance when projects provided multiple entry points, transparent process-based assessment, and inclusive role distribution. Collectively, the evidence positions PBL as a high-leverage instructional approach for competency-oriented secondary education, while emphasizing that its long-term effectiveness depends on deliberate design, assessment alignment, and institutional support for sustained implementation quality.

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