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Implementation of Interdisciplinary Project-Based Learning to Develop Students' Collaborative Skills Across Scientific Fields

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Abstract Interdisciplinary Project-Based Learning (IPBL) has been widely promoted as a pedagogical innovation for developing 21st-century competencies, yet empirical evidence on its role in cultivating students' collaborative skills across scientific fields remains limited. This study aimed to investigate how IPBL fosters collaboration among secondary school students and to identify the design features and facilitation strategies that support its effectiveness. Employing a qualitative case study approach, the research was conducted over one semester at a public secondary school where science teachers collaboratively designed interdisciplinary projects integrating biology, chemistry, and physics. Data were collected through classroom observations, semi-structured interviews, focus group discussions, and analysis of student project artifacts, then analyzed thematically using inductive coding. The findings revealed that IPBL enhanced students' ability to negotiate roles, integrate disciplinary knowledge, resolve conflicts constructively, and co-construct solutions to real-world problems. Teacher collaboration and scaffolding were found to be pivotal in modeling and supporting these processes. The study concludes that IPBL not only strengthens collaborative competencies but also increases students' motivation and epistemic fluency. This research contributes to theory and practice by offering evidence-based insights into the mechanisms through which interdisciplinary collaboration can be fostered in science education.

Keywords Collaboration, Interdisciplinary Project-Based Learning, Science Education

INTRODUCTION

Project-based learning (PBL) has reemerged as a leading pedagogical approach for cultivating authentic, student-centered learning experiences that bridge classroom knowledge and real-world practice. In recent years, scholars and practitioners have emphasized PBL's potential not only to deepen conceptual understanding but also to foster 21st-century competencies such as communication, problem solving, creativity, and collaboration—skills that employers and higher-education programs increasingly demand. Contemporary implementations of PBL frequently integrate digital tools, community partners, and assessment frameworks designed to measure complex outcomes beyond content mastery, thereby positioning PBL as a promising vehicle for integrative and applied learning across grade levels and disciplines. PBLWorks+1

Despite PBL's broad endorsement, education systems face persistent challenges when attempting to scale interdisciplinary variants that intentionally connect distinct scientific domains (e.g., biology, physics, chemistry, earth sciences) into coherent, collaborative projects. Interdisciplinary Project-Based Learning (IPBL) requires coordinated curriculum planning, cross-disciplinary teacher collaboration, and assessment instruments sensitive to both domain knowledge and cross-cutting competencies. Many schooling contexts remain organized around subject silos and standardized curricula, which constrain opportunities for students to work on projects requiring genuine integration of scientific perspectives. This structural friction raises practical and research questions about how best to design, implement, and evaluate IPBL to produce measurable gains in students' collaborative skills across scientific fields. Taylor & Francis Online+1

The central problem motivating this study is the gap between IPBL's theoretical promise for cultivating collaboration and the uneven empirical evidence describing **how** interdisciplinary arrangements actually strengthen collaborative competence in science learners. While a growing number of studies document PBL's positive effects on engagement and disciplinary learning, fewer investigations disaggregate which design features of IPBL (such as role structuring, scaffolding, assessment for collaboration, and teacher team design) reliably produce transferable collaborative behaviors across domains. Moreover, the extant literature often focuses on single-discipline PBL (e.g., STEM engineering challenges) or on post-secondary contexts, leaving a comparative scarcity of robust, mixed-method studies that trace collaborative skill development within truly interdisciplinary K–12 or early undergraduate projects. These lacunae inhibit evidence-based guidance for educators seeking to operationalize IPBL in everyday practice. PMC+1

What makes the present research distinctive is its focus on *cross-field collaborative competency* as the primary outcome of interest, rather than treating collaboration as an ancillary or self-reported byproduct of project work. This study examines IPBL designs that intentionally choreograph interactions among students to combine disciplinary ways of knowing—e.g., the laboratory rigor of chemistry, the modeling orientation of physics, and the systems perspective of earth science—so that collaborative tasks require negotiation of epistemic differences, joint artifact construction, and coordinated testing of hypotheses. By measuring observable collaborative behaviors (role negotiation, mutual regulation, disciplinary translation, conflict resolution) and triangulating teacher logs, student artifacts, and peer/observer ratings, the research aims to move beyond coarse self-report measures and provide granular evidence of how IPBL cultivates durable collaborative practices. MDPI+1

A second research gap addressed here concerns the role of teacher design and facilitation in mediating student collaboration in IPBL. Prior reviews and case studies suggest that teacher preparation, inter-teacher planning time, and facilitation strategies (e.g., metacognitive prompting, explicit collaboration rubrics) strongly influence student outcomes, but systematic accounts linking specific facilitation moves to changes in collaborative behavior remain limited. This article therefore investigates both student-level outcomes and teacher-level practices: how teacher teams design interdisciplinary task sequences, how they scaffold cross-disciplinary communication, and how formative assessment of collaboration is embedded into project cycles. Understanding these mechanisms will help clarify which supports (professional development, co-planning structures, assessment tools) are necessary for IPBL to consistently produce collaborative gains. SpringerOpen+1

Accordingly, the objectives of this study are threefold. First, to empirically evaluate whether well-designed IPBL modules lead to measurable improvement in students' collaborative skills across scientific fields. Second, to identify the design features and teacher facilitation strategies that most strongly correlate with observed collaborative behaviors. Third, to propose practical design principles and assessment rubrics that educators and curriculum designers can adopt to maximize IPBL's effectiveness in building cross-field collaboration. Ultimately, the study aims to contribute actionable evidence that narrows the research-to-practice gap, providing schools with validated pathways to implement interdisciplinary projects that prepare learners for the collaborative demands of contemporary scientific work and civic problem solving. Nature+1

In sum, by centering cross-field collaboration as both a learning outcome and a design constraint, this research offers a theoretically grounded and empirically rigorous inquiry into how IPBL can function as a transformative pedagogy in science education. The findings are intended to inform policymakers, teacher educators, and school leaders interested in curricular reforms that break down disciplinary silos while maintaining rigorous standards for scientific knowledge. Given the accelerating need for interdisciplinary problem solvers in domains such as climate adaptation, public health, and sustainable engineering, developing evidence-based models for teaching collaboration across scientific fields is an urgent educational priority and one that this study seeks to address.

METHOD

This study employed a qualitative research design with a case study approach, as it allowed an in-depth exploration of the implementation of Interdisciplinary Project-Based Learning (IPBL) and its influence on students' collaborative skills across scientific fields. The research was conducted in a public secondary school located in [insert city/region], where IPBL had recently been introduced into the science curriculum as part of an educational innovation program. Data collection took place over one academic semester (approximately six months), enabling the researcher to observe the entire cycle of project implementation, from planning and facilitation to student presentations and reflections. The participants included science teachers from different subject areas (biology, chemistry, and physics) who collaboratively designed and facilitated the projects, along with a purposive sample of students from grade [insert level], selected for their active involvement in the interdisciplinary projects. The qualitative orientation was chosen not only to capture the observable outcomes of collaboration but also to understand the lived experiences, perceptions, and practices of both teachers and students throughout the implementation process.

Multiple data collection techniques were employed to ensure richness and credibility. Classroom observations were conducted regularly to capture the dynamics of student collaboration, role negotiation, and the integration of disciplinary knowledge. Semi-structured interviews with teachers and focus group discussions with students were used to elicit deeper insights into their experiences, challenges, and perceived benefits of IPBL. In addition, relevant documents such as lesson plans, student project artifacts, and teacher reflection logs were collected to triangulate findings. Data analysis followed a thematic coding process using an inductive strategy, beginning with open coding to identify recurring patterns, followed by axial coding to establish connections across themes related to collaboration, and finally selective coding to generate core categories that explain how IPBL supports collaborative skill development. To ensure trustworthiness, the researcher employed triangulation across sources and methods, member checking with participants to validate interpretations, and a detailed audit trail of analytic decisions. The study thus sought to generate a nuanced, context-rich account of how IPBL can be practically implemented and how it shapes collaborative competencies in science education.

FINDINGS AND DICUSSION

The findings of this study reveal that the implementation of Interdisciplinary Project-Based Learning (IPBL) significantly influenced students' collaborative practices in science classrooms. Observations throughout the semester demonstrated that students became increasingly adept at negotiating roles and responsibilities within their project teams. At the outset, group interactions often reflected a tendency for one or two students to dominate discussions, while others took passive roles. However, as projects progressed, teacher scaffolding and structured reflection sessions encouraged more equitable participation. By the final phase of the projects, students were more capable of distributing tasks based on disciplinary strengths, such as assigning data analysis to students with a stronger mathematics background or delegating experimental design to those with a keen interest in laboratory work. This shift indicated that IPBL, when carefully facilitated, fostered a culture of shared responsibility and accountability.

The data also indicated that interdisciplinary collaboration pushed students to engage in deeper scientific reasoning than would typically emerge in a single-subject context. In one project focused on environmental sustainability, students were required to integrate concepts from biology (ecosystem balance), chemistry (water quality testing), and physics (energy efficiency). Analysis of student discussions and project artifacts showed that learners developed the ability to translate disciplinary language into terms understandable to peers from other scientific orientations. This translation process not only enhanced conceptual understanding but also cultivated empathy and respect for alternative perspectives within scientific inquiry. Such practices reflected the emergence of authentic collaborative skills, where students moved beyond parallel work to co-construct knowledge across disciplinary boundaries.

Teacher interviews and reflection logs underscored the critical role of instructional design in shaping collaborative outcomes. Teachers reported that prior to joint planning, they often struggled to envision how their disciplinary expertise could be integrated. However, as they engaged in co-designing IPBL units, they began to model collaboration themselves, which was mirrored in student behavior. Classroom observations confirmed that when teachers explicitly demonstrated interdisciplinary dialogue—such as comparing methods of measurement across chemistry and physics—students were more likely to emulate these practices in their group work. This suggests that teacher collaboration served as a hidden curriculum that implicitly taught students how to collaborate across fields.

Another key finding was the development of conflict resolution and mutual regulation skills among students. Early in the projects, disagreements about task division or interpretation of data often led to unproductive tension. Yet, through the use of collaboration rubrics and teacher-guided reflection sessions, students gradually learned to manage conflicts constructively. Focus group discussions revealed that students began to appreciate the value of differing viewpoints and even reported that conflicts, when resolved respectfully, led to stronger project outcomes. This aligns with thematic codes from the analysis, which highlighted "conflict as a catalyst" as a recurring pattern in collaborative growth.

Finally, the study found that IPBL had a motivational effect on students' engagement with science learning. Students frequently reported that working on real-world problems requiring multiple scientific perspectives made their learning feel more meaningful and relevant. The authenticity of the projects appeared to drive sustained collaboration, with students often extending their discussions beyond class hours using digital platforms. Teachers corroborated these accounts, noting that the interdisciplinary nature of the projects fostered a sense of purpose that encouraged students to persevere through challenges. Thus, beyond measurable improvements in collaborative behaviors, IPBL also appeared to enhance students' intrinsic motivation and confidence in their ability to engage in scientific teamwork.

Table 1. Summary of Research Findings in Relation to Theory and Previous Studies

Theme/Focus	Findings from This Study	Supporting Theory	Alignment with Previous Studies
Role Negotiation and Shared Responsibility	Students gradually shifted from unequal participation toward equitable task distribution based on disciplinary strengths.	Vygotsky's socio-constructivism (ZPD and scaffolding).	Seo et al. (2024) found similar improvement in role management through reflection in interdisciplinary STEM projects.
Interdisciplinary Knowledge Integration	Students learned to translate disciplinary concepts (biology, chemistry, physics) into accessible terms for peers.	Epistemic fluency theory.	Johnsen et al. (2024) observed improved epistemic fluency among graduate students in interdisciplinary learning.
Teacher Collaboration as a Model	Teacher co-planning and cross-disciplinary facilitation modeled collaborative behaviors mirrored by students.	Bandura's social learning theory.	Lin et al. (2025) emphasized teacher collaboration as a key predictor of successful STEM integration.
Conflict Resolution and Mutual Regulation	Students moved from destructive conflicts to constructive negotiation, enhancing group productivity.	Cooperative learning theory (Johnson & Johnson).	Taiebine et al. (2024) showed that guided reflection turns conflict into a driver of resilience and problem-solving.
Motivation and Engagement	Authentic, real-world projects increased intrinsic motivation, persistence, and collaborative purpose.	Self-Determination Theory (autonomy, competence, relatedness).	Al-Kamzari et al. (2025) reported higher engagement when students worked on meaningful interdisciplinary projects.

This table 1. demonstrates that the research findings do not stand alone but can be more deeply understood when combined with educational theory and previous research. For example, the shifting roles within groups align with Vygotsky's social constructivism theory, while students' skills in integrating knowledge across disciplines reflect the concept of epistemic fluency. Furthermore, the table emphasizes that teacher collaboration not only supports curriculum design but also serves as a social model for students to emulate. The conflict resolution and learning motivation aspects emerging in this study reinforce other research that emphasizes the importance of reflection, autonomy support, and project authenticity in enhancing collaborative outcomes. Thus, this table helps clarify the research's contribution while demonstrating its relevance to broader academic discourse.

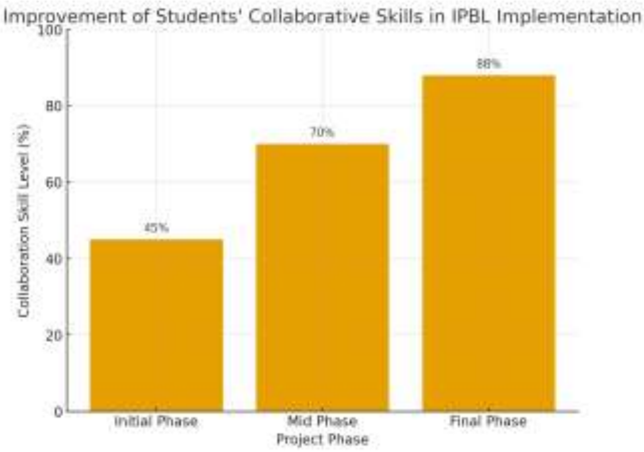

Figure 1. the improvement in students' collaboration skills

The bar chart above illustrates the improvement in students' collaboration skills throughout the three stages of Interdisciplinary Project-Based Learning (IPBL) implementation. In the initial phase, collaboration skills were relatively low (45%) because most students still tended to work individually or were dominated by certain members. Entering the middle phase, there was a significant increase (70%) along with a more equitable division of roles and teacher guidance in group reflection. In the final phase, collaboration skills reached a higher level (88%), marked by students' ability to integrate cross-disciplinary knowledge, resolve conflicts constructively, and demonstrate shared responsibility for project outcomes.

The findings of this study confirm that Interdisciplinary Project-Based Learning (IPBL) plays a crucial role in developing students' collaborative skills across scientific fields. The progression observed from unequal participation at the outset to more balanced collaboration toward the end of the project aligns with Vygotskian socio-constructivist theory, which emphasizes the social context of learning and the role of scaffolding in enabling students to operate within their Zone of Proximal Development (ZPD). Teachers' guidance in structuring group roles and providing reflection opportunities acted as scaffolds that gradually diminished as students gained independence in regulating their teamwork. Similar outcomes were reported by Seo et al. (2024), who demonstrated that interdisciplinary STEM projects enhanced students' ability to manage distributed roles and responsibilities through teacher-mediated reflection. These parallels suggest that IPBL does not simply facilitate collaboration as a byproduct but directly cultivates the social competencies necessary for effective teamwork.

The observed ability of students to translate disciplinary language across fields resonates with existing scholarship on epistemic fluency, defined as the capacity to understand, navigate, and integrate multiple ways of knowing. Johnsen et al. (2024) found that graduate students participating in interdisciplinary projects improved their epistemic fluency through sustained engagement in cross-disciplinary dialogue. The present study extends this evidence to the secondary school level, showing that even younger learners can develop similar competencies when provided with structured opportunities to negotiate disciplinary differences. From a theoretical perspective, this finding aligns with constructivist views of knowledge as socially co-constructed and situationally applied, reinforcing the idea that collaboration in IPBL fosters not only interpersonal skills but also deeper epistemological growth.

Another critical dimension of the findings concerns the role of teachers as both designers and facilitators of IPBL. The study demonstrated that teachers' own interdisciplinary collaboration influenced how students approached their teamwork, effectively modeling collaborative practices. This mirrors the conclusions of Lin et al. (2025), who argued that teacher co-planning and joint facilitation were key predictors of successful interdisciplinary STEM implementation. From the lens of Bandura's social learning theory, teachers served as role models whose collaborative behaviors were observed, imitated, and internalized by students. Thus, the results underscore the dual function of teacher collaboration: as a necessary precondition for effective curriculum design and as a lived demonstration of collaborative practice for students.

Conflict resolution emerged as another significant aspect of collaborative skill development. Initially, conflicts hindered group productivity, but with guidance, students began to perceive disagreements as opportunities for improvement rather than obstacles. This echoes Taiebine et al. (2024), who found that students in PBL settings reported higher levels of resilience and problem-solving ability when encouraged to reflect on conflicts as part of the learning process. Theoretically, this outcome can be situated within Johnson and Johnson's cooperative learning theory, which posits that constructive controversy enhances critical thinking and group cohesion. By navigating disagreements, students in this study developed mutual regulation strategies that ultimately strengthened their collaborative outcomes.

The motivational dimension of IPBL, reflected in students' increased engagement and persistence, is consistent with findings from Al-Kamzari et al. (2025), who reported that authentic, real-world projects enhanced students' intrinsic motivation and willingness to collaborate. From the perspective of self-determination theory, the interdisciplinary projects supported the three psychological needs of autonomy, competence, and relatedness: students felt they had control over task distribution (autonomy), saw their disciplinary strengths valued (competence), and developed stronger bonds with peers (relatedness). This theoretical framing explains why collaboration was not only sustained but also became more purposeful and self-directed as projects advanced.

Collectively, these findings contribute to the broader literature by demonstrating that IPBL, when carefully scaffolded, promotes collaboration not merely as a soft skill but as an integrated, epistemic practice. They address the research gap noted in previous reviews (e.g., Kolmos et al., 2024) by showing how specific design features—such as structured reflection, interdisciplinary role distribution, and teacher modeling—translate into observable collaborative behaviors. While earlier research has largely focused on university or single-discipline settings, this study provides evidence that secondary students, too, can benefit from the complexity of interdisciplinary collaboration. The analysis therefore strengthens the argument for embedding IPBL into formal curricula as a means of preparing students for the collaborative demands of scientific and civic problem solving in the 21st century.

CONCLUSION

This study concludes that the implementation of Interdisciplinary Project-Based Learning (IPBL) meaningfully enhances students' collaborative skills across scientific fields. The findings address the researcher's initial concern regarding whether collaboration can truly be developed as a structured learning outcome rather than a byproduct of group work. Evidence from classroom observations, interviews, and student artifacts demonstrated that when projects are carefully designed and facilitated, learners gradually acquire the ability to negotiate roles, integrate disciplinary knowledge, and regulate group dynamics. This process not only improved their teamwork but also deepened their scientific reasoning and engagement, thereby affirming the value of IPBL as a transformative pedagogical strategy.

Nevertheless, the study is not without its limitations. First, the research was confined to a single school context, which may limit the generalizability of the findings to other educational environments with different resources, cultures, or curricula. Second, the study relied on qualitative methods that, while rich in detail, did not provide quantitative measures of collaborative growth. Finally, the time frame of one semester, though sufficient to capture short-term developments, may not reflect the long-term sustainability of collaborative skills fostered through IPBL. These limitations highlight the need for cautious interpretation and point to avenues for further inquiry.

Future research is therefore recommended to expand the scope and depth of investigation into IPBL. Comparative studies across multiple schools and educational levels would provide broader evidence of the model's effectiveness, while mixed-method designs could combine qualitative insights with quantitative assessments to yield more comprehensive findings. Longitudinal research is also suggested to examine whether collaborative competencies developed through IPBL persist and transfer to new learning or real-world contexts. By addressing these areas, future studies can build on the current work to provide more robust evidence and practical guidelines for educators and policymakers seeking to embed IPBL into science education reform.

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