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## **Implementing Project-Based Learning in Undergraduate STEM: Outcomes and Effectiveness**

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### **ABSTRACT**

*This study examined the use of Project-Based Learning (PBL) in undergraduate STEM courses at a Hispanic-Serving Institution, focusing on the development of problem-solving, critical thinking, and teamwork skills. The sample included a high proportion of Hispanic students. Across four semesters, students ( $n = 332$ ) completed self-report retrospective pretest and posttest surveys; results indicated significant gains in all three skill areas, with effect sizes in the small to moderate range (Cohen's  $d = 0.23$ – $0.30$ ). Findings indicate that participation in PBL was associated with measurable, though incremental, improvements in skills central to*

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*STEM learning. Future work should incorporate longitudinal designs, cross-institutional comparisons, and performance-based assessments.*

**Keywords:** Critical Thinking, Experiential Learning, Hispanic-Serving Institutions (HSIs), Problem Solving, Project-Based Learning (PBL), STEM Education, Teamwork

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## INTRODUCTION

Undergraduate research programs offer significant benefits not only to students, but also to faculty mentors and academic institutions. Research has demonstrated its positive influence on career development, student preparedness, self-efficacy (Matelski et al., 2025), and retention within Science, Technology, Engineering, and Math (STEM) disciplines (Bangera & Brownell, 2014; Jordan et al., 2014; Strobel & van Barneveld, 2009) and graduation (Dong et al., 2021). When research or problem-solving components are integrated alongside a strong academic foundation, students are pushed to think critically and sharpen both their written and oral communication skills. Many of the barriers that commonly hinder student participation, such as work obligations, hesitation in approaching faculty, limited awareness of research opportunities, and economic or personal challenges, can be effectively addressed by embedding these high-impact practices directly into required coursework (Bangera & Brownell, 2014). Project-Based Learning (PBL) has emerged as a particularly effective approach to experiential learning in the classroom. Markham et al. (2003) described PBL as "an extended inquiry process structured around complex, authentic questions and carefully designed products and tasks." PBL has been widely adopted across numerous fields, including medicine, engineering, education, economics, and business (Capraro et al., 2013). It is worth noting the distinction between problem-based and project-based learning: the former emphasizes process, while the latter centers on producing a tangible outcome or solution. PBL projects can be thoughtfully designed to generate meaningful data that informs future student work while simultaneously advancing the faculty mentor's own research agenda (Shortlidge et al., 2017).

The effective implementation in STEM contexts demands a skilled teaching force capable of designing learning experiences that fully unlock student potential. When embedded within undergraduate curricula, PBL typically engages large groups of students in sustained inquiry that unfolds over several weeks. Students tackle relevant scientific problems or questions, and their input is central to shaping the direction of the project. This participatory structure gives students a genuine sense of ownership over driving questions, proposed solutions, and collaborative responsibilities. Projects also carry an authentic dimension — whether through adherence to the scientific method or engagement with real-world scientific challenges. Reflection is another cornerstone of PBL, prompting students to evaluate the quality of their work, confront obstacles, and consider what they are learning, how they are learning it, and why it matters both within and beyond the curriculum. Faculty play an active role by providing feedback and offering students the chance to revise their work (Bell, 2010). The process culminates in students presenting their findings to an audience outside the classroom (Larmer et al., 2015a).

Ultimately, PBL is a powerful vehicle for building 21st-century competencies, including critical thinking, problem solving, teamwork, time management, and self-direction. Beyond conceptual understanding, it nurtures essential life skills such as creativity, communication, responsibility, and a deeper awareness of how learning itself works (Bell, 2010). Furthermore, PBL seeks to integrate engineering design principles across K-16 education, helping students draw meaningful connections to STEM careers and the professional world that awaits them (Capraro et al., 2013). Today's job market increasingly favors college graduates who bring both interdisciplinary knowledge and hands-on experience to the table. This shift reflects a broader recognition that the complex challenges facing society, industry, and business demand effective collaboration across multiple fields, including STEM.

The STEM grant from this institution was established with the goal of improving persistence and graduation rates among low-income and Hispanic students. Its core objectives focus on strengthening STEM literacy and critical thinking by weaving PBL into existing course curricula, creating opportunities for large groups of students to collaborate on meaningful projects and, in doing so, build a thriving community of emerging STEM professionals. Funded by the U.S. Department of Education, the goal of this project was to increase the number of Hispanic and low-income students earning degrees in one of six STEM fields: Biology, Psychology, Mathematics, Computer Science, Computer Information Science, and Cybersecurity. This institution is a federally designated HSI, and its student body is notably diverse. In 2020, Hispanic students made up the largest share of enrollment at 38%. More than half of all undergraduates (60%) are first-generation college students, and the financial need among this population is

significant — 85% of full-time undergraduates received financial aid. In 2020, overall retention rates at this institution (74%) were comparable to or better than peer institutions; however, retention among Hispanic students declined in the wake of the COVID-19 pandemic. Compounding this challenge, persistence and retention rates in STEM majors lag considerably behind those in other fields. Through this grant initiative, this study placed this high-impact approach at the center of our work — designing curricula that cultivated students' awareness of interdisciplinary project-based learning while preparing them to engage meaningfully with the kinds of complex, real-world problems they will encounter in their careers. The PBL implementation was carried out by a group of faculty who had participated in sustained professional development and revised their course to include PBL. This training was conducted within a cohort model, allowing instructors to collaborate with colleagues, share best practices, and refine their instructional strategies. In this regard courses in STEM disciplines were selected to redesign using PBL. This was carried out to facilitate interdisciplinary collaboration among students and faculty to solve challenges in topics such as environment, sustainability, healthcare, education, communications, among other areas.

## **LITERATURE REVIEW**

### **Project-Based Learning in Higher Education: Foundations, Frameworks, and Learning Outcomes**

Project-based learning (PBL) in higher education repositions the instructor from a content deliverer to a learning facilitator (Mutanga, 2024). Through engagement in real-world inquiries, students tackle meaningful problems that demand collaboration, critical analysis, and the application of disciplinary knowledge (Guo et al., 2020). Theoretically, PBL draws on social constructivism and experiential learning: learners actively construct understanding through purposeful activity (Jaleniauskiene & Venckiene, 2025), while Kolb's cycle, which encompasses concrete experience, reflective observation, abstract conceptualization, and active experimentation, deepens this understanding across recurring phases of inquiry (Choshi, 2025). Compared with conventional lecture-based teaching, PBL builds competencies through authentic problem-solving (Mutanga, 2024). Students participating in PBL demonstrate greater development in critical thinking, creative problem-solving, and self-directed learning (Guo et al., 2020), and consistently outperform peers on applied assessments while sustaining longer-term retention (Bell & Bell, 2020). These outcomes can be attributed to the cognitive demands inherent in PBL, which require students to draw on prior knowledge, integrate new information into existing understanding, and apply learning to unfamiliar situations. Collectively, these processes

strengthen long-term memory and support the transfer of knowledge to new contexts.

## **PBL in STEM Context: Benefits and Evidence**

Previous research has demonstrated that PBL in STEM enhances critical thinking, conceptual understanding, and key 21st-century skills (Simamora, 2024). A meta-analytic review of STEM project-based learning found a large and statistically significant positive effect on students' creative thinking, although effects on problem-solving and specific design features were not evaluated in this study (Kwon & Lee, 2025). PBL also develops students' collaboration and communication skills, though logistical challenges require structured support to be effectively managed (Mutanga, 2024). Real-world projects increase student motivation, engagement, and ownership of learning (Jaleniauskiene & Venckiene, 2025), and longitudinal evidence suggests that graduates who experience PBL enter professional practice with stronger career readiness (Naseer et al., 2025).

PBL scholarship has grown eightfold between 2014 and 2024, with growth concentrated particularly in STEM and higher education (Mota et al., 2025). This expansion reflects a growing recognition that solely lecture-heavy instruction leaves graduates underprepared in professional capacities, problem-solving, and collaboration. In response to these preparation gaps, STEM programs have increasingly adopted PBL precisely because it immerses students in complex, ill-structured problems that demand the integration of technical knowledge and real-world judgment (Guo et al., 2020). Taken together, PBL represents an evidence-based strategy for improving student outcomes in STEM higher education.

## **Implementation Challenges: Barriers and Implementation Complexities**

As much as the evidence in favor of PBL is compelling, there are three implementation hurdles that routinely limit its reach and impact. First, time: carving out sustained blocks for meaningful project work while “covering” dense conceptual content, especially in fast-paced STEM courses, creates a real tension with traditional coverage models (Evenddy et al., 2023). Second, assessment: robust PBL requires multidimensional evaluation that is both valid and reliable across cognitive (e.g., questionnaires, rubrics, tests), affective (e.g., interviews, observations, and self-reflection journals), and behavioral outcomes such as skills and engagement (Guo et al., 2020). Third, collaboration: uneven participation can emerge when accountability is underspecified, discouraging disengaged students and overburdening their more committed peers (Mutanga, 2024). In practice, these pressures interact, and limited time can shorten reflection and feedback cycles. As a result, the complexity of assessment can overwhelm instructors new to PBL.

Addressing them demands intentional course architecture: explicit timeboxing and milestone planning, transparent rubrics aligned to learning outcomes, and clear team contracts with role rotation and peer feedback. Until such supports are commonplace, PBL's proven benefits will continue to outpace its adoption in higher education (Evenddy et al., 2023; Guo et al., 2020; Mutanga, 2024). Faculty readiness and targeted professional development are frequently underestimated barriers to successful PBL adoption. Teaching PBL well requires a distinct instructional repertoire from traditional lecture-based approaches: facilitating inquiry instead of delivering answers, engineering projects with well-calibrated scaffolds and complexity, providing timely, actionable feedback across iterative cycles, and skillfully managing student-centered classroom dynamics (Evenddy et al., 2023).

Across departments, many instructors step into PBL without formal preparation and need sustained professional development before they become truly fluent in facilitation, project design, and feedback cycles (Evenddy et al., 2023). Adoption is further slowed by institutional frictions - tight scheduling, limited resources, and curriculum governance that makes change cumbersome. Together, these realities help explain why PBL remains underused in higher education even with strong evidence for its effectiveness (Guo et al., 2020).

## **Research Gap**

Much of the evidence related to PBL is derived from studies conducted in predominantly traditional four-year or research-intensive institutions, leaving an important gap in understanding how PBL functions within minority-serving contexts, particularly Hispanic-Serving Institutions (HSIs). HSIs play a critical role in educating a large and growing proportion of Hispanic/Latino students in the United States, many of whom are underrepresented in STEM fields. In these contexts, pedagogical approaches must do more than improve academic skills; they must also support student confidence, belonging, and persistence. Although PBL has been proposed as a high-impact practice, limited research has examined its effectiveness specifically for underrepresented STEM populations within HSIs, or how it may contribute to broader equity and retention goals. This study addresses these gaps by examining the implementation of PBL designed to support student success in STEM pathways. By studying a diverse group of students at an HSI, this research adds to what we know about PBL in three important ways. First, it shows that PBL works well in a minority-serving institution, not just in the types of schools most often studied. Second, it focuses on underrepresented STEM students and helps explain how PBL can better support those who have been historically had rates of lower participation and attainment. Third, it looks at how PBL was associated with perceived student gains, especially problem solving,

critical thinking and teamwork helping us understand not just if PBL works, but how and why it helps students succeed.

Next, most studies on PBL focus on general outcomes and test scores, but they rarely explore how students personally experience the learning process (Mutanga, 2024). In particular, traditional assessments tend to overlook how students perceive their own skill development within real PBL tasks. This is an important gap, as most existing research relies on achievement scores or instructor observations, leaving students largely out of the discussion, despite being best placed to report on their own learning experiences (Guo et al., 2020; Mutanga, 2024). Therefore, capturing students' reflective and self-assessed perspectives through a retrospective pretest-posttest survey approach offers a valuable way to better understand how PBL shapes skill development from the learner's point of view.

To address this gap the present study adopts a student-centered, retrospective pretest-posttest survey approach. Rather than relying on overall outcomes or instructor perspectives, this design foregrounds students' reflections on their own development, allowing for a more fine-grained understanding of how skills evolve within authentic PBL contexts.

The research questions guiding this study are:

RQ 1: Is participation in a PBL course associated with an increase in students' self-reported problem-solving skills?

RQ 2: Is participation in a PBL course associated with an increase in students' self-reported critical thinking skills?

RQ 3: Is participation in a PBL course associated with an increase in students' self-reported teamwork skills?

## **RESEARCH METHOD**

The Institutional Review Boards at this institution approved the survey data collection for PBL as part of the evaluation of the program, which ultimately was rated as Exempt.

### **Sampling Procedure**

This study used data collected from student surveys administered to students enrolled in PBL courses at the conclusion of the course. Data were collected across semesters (Fall 2023, Spring 2024, Fall 2024, and Spring 2025), for a total of four data collection periods. Participants were asked to rate both posttest ratings as well as retrospective pretest ratings at the conclusion of their PBL course to assess students' self-reported ratings of skills they gained in their course.

Retrospective pretest and posttest surveys were administered given the limitations students often have regarding the likelihood of overestimation of their skills on a true pretest. Specifically, a response shift bias is a well-documented phenomenon (Howard & Daily, 1979) where individuals shift in their understanding of a concept over time, hence rendering a true pretest rating inaccurate. Often, retrospective pre-tests are preferable for those programs where participants will benefit from reflecting on their growth during the program and are potentially less likely to be biased in these situations (Hill & Betz, 2005).

## **Inclusion Criteria**

Students enrolled in any participating section of a PBL course over four semesters (Fall 2023 - Spring 2025) were allowed to participate in the study. Students were required to sign a consent form before completing the survey. No additional exclusion criteria were present.

## **Expected Demographic Characteristics**

It was expected that participating students' demographic characteristics would reflect the overall population of Mercy students. Specifically, we expected that there would be approximately 70% female students included in the sample. In addition, we expected to include approximately 44% of Hispanic students in the sample.

## **Participants**

A total of 332 out of 510 eligible students responded to the survey upon completing their PBL course project, representing a response rate of 65%. Two students did not have a matched pre-post response for the critical thinking measure; hence, the sample size for this measure was  $n = 330$ . In addition, these two students also did not have a response for the teamwork measure, and eight students in one course worked independently on the project; therefore, their responses were not included in the teamwork measure. Consequently, the sample size for teamwork was  $n = 322$ . Participants were students enrolled in a course in which PBL was implemented as part of the STEM project. Participation in the survey was confidential.

The reported demographic characteristics for participants reflect the analytic sample. Five students completed the assessment in more than one course. These students were included once based on their first instance of assessment completion. Consequently, course discipline counts reflect the first PBL course in which each of the five students completed the survey. Most students were female (76.5%), and

more than half were Hispanic (53.6%). The most frequently represented course discipline was biology (46.7%), followed by psychology (22.6%).

**Table 1**  
*Final Sample Demographic Characteristics*

|                      |                                   | N<br>(n=332) | Percent |
|----------------------|-----------------------------------|--------------|---------|
| Sex                  | Female                            | 254          | 76.5%   |
|                      | Male                              | 78           | 23.5%   |
| Ethnicity/Race       | Hispanic                          | 178          | 53.6%   |
|                      | Black                             | 74           | 22.3%   |
|                      | White                             | 30           | 9.0%    |
|                      | Asian                             | 22           | 6.6%    |
|                      | Unknown                           | 16           | 4.8%    |
|                      | Two or More Races                 | 11           | 3.3%    |
|                      | American Indian or Alaskan Native | 1            | 0.3%    |
| Course<br>Discipline | Biology                           | 155          | 46.7%   |
|                      | Psychology                        | 75           | 22.6%   |
|                      | Mathematics                       | 32           | 9.6%    |
|                      | Physics                           | 25           | 7.5%    |
|                      | Chemistry                         | 23           | 6.9%    |
|                      | Computer Information Science      | 22           | 6.6%    |

**Measures**

*Problem Solving*

The problem-solving measure consisted of the four-question problem solving subscale from the Life Skills Ability Scale (Cronin et al., 2021). For the posttest

rating, students were asked to think about their problem-solving skills after completing the course project and indicate the extent to which they agreed or disagreed with each item. Students rated each item on a five-point Likert-type scale: 1 = *Strongly disagree*; 2 = *Disagree*; 3 = *Neutral*; 4 = *Agree*; 5 = *Strongly agree*. After completion of the posttest scale, participants were then asked to think about themselves before starting the project and rate corresponding items as a retrospective pretest. Students rated each item on the same five-point Likert-type scale. The internal consistency of the scale as measured at posttest by Cronbach's  $\alpha$  (.91) was closely aligned to the published  $\alpha$  (.87).

### *Critical Thinking*

The critical thinking measure consisted of five questions adapted from the critical thinking subscale of the Motivated Strategies for Learning Questionnaire (Pintrich et al., 1991). Each of the five items from the subscale were adapted to remove reference to a particular course. For example, the original item "I try to play around with ideas of my own related to what I am learning in this course" was revised to "I try to play around with ideas of my own related to what I am learning." Items were the same for both the retrospective pretest and posttest, however the instructions varied. Specifically, the posttest first asked participants to "Please indicate the extent to which the following statements are true of you AFTER completing the course project." The pretest instructions then asked participants to "Please indicate the extent to which the following statements are true of you BEFORE participating in the course project." Participants rated each item on the same seven-point Likert-type scale: 1 = *Not at all true of me*; 2; 3; 4; 5; 6; 7 = *Very true of me*. Internal consistency of the scale as measured at pretest by Cronbach's  $\alpha$  (.93) and posttest by Cronbach's  $\alpha$  (.88) were closely aligned to the published  $\alpha$  (.80).

### *Teamwork*

All students were asked to rate eight items comprising a teamwork scale published by Lower et al. (2017). Participants were provided with instructions to think about their teamwork skills after completing the course project and indicate the extent to which each item was true of them at posttest. Students rated each item on a five-point Likert-type scale: 1 = *Not at all true*; 2; 3 = *Somewhat true*; 4; 5 = *Really true*. After completion of the posttest scale, participants were then asked to think about themselves before starting the project and rate corresponding teamwork items as a retrospective pretest. Students rated each item on the same five-point Likert-type scale. The internal consistency of the scale as measured at posttest by Cronbach's  $\alpha$  (.90) was closely aligned to the published  $\alpha$  (.88).

## Procedure

The survey questions were programmed into an online survey software platform (i.e., Alchemer) by the project's external evaluation team. A member of the evaluation team sent the survey link and a QR code to the participating faculty members; the faculty members then shared with students via Blackboard and/or allowed students to complete the survey after their final presentations in class. All participating PBL course students were provided with an opportunity to complete the survey.

Demographic data was requested from this institution's Institutional Research Department based on the list of students enrolled in PBL courses for each term. Demographic data were provided to the external evaluation team and then combined with survey data into a dataset for cleaning.

## Data Cleaning

Survey responses from all participating sessions were combined into one data file for analysis. Composite variables were calculated by combining questions for each construct of interest (e.g., problem-solving) for both retrospective pretest and posttest scores. Given the range of courses in which PBL has been implemented over the two years, some students were enrolled in more than one PBL course and therefore completed the survey more than once. For these students ( $n = 5$ ), their first response was included in cumulative analysis. In addition, survey responses from five students who did not successfully complete their PBL course were removed.

## RESULTS

To determine whether students increased their self-ratings for each of the constructs (i.e., problem-solving, critical thinking, teamwork) from retrospective pretest to posttest, this study employed a series of paired-samples  $t$ -tests to compare the ratings on each of the composite variables.

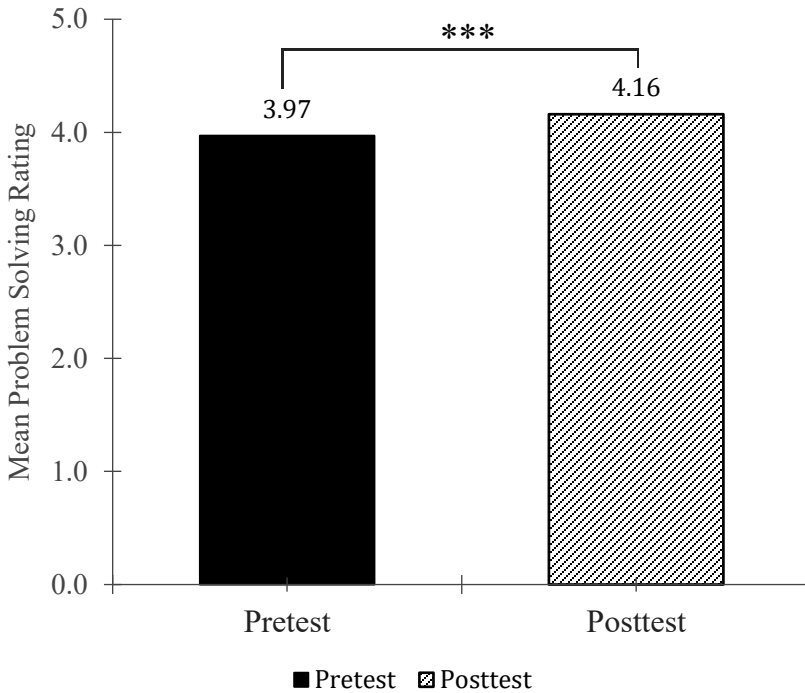
### Problem Solving

*RQ1: Is participation in a PBL course associated with an increase in students' self-reported problem-solving skills?*

A paired-samples  $t$ -test indicated that PBL students reported a statistically significant increase in their self-reported problem-solving scores at posttest ( $M = 4.16$ ,  $SD = 0.79$ ) compared to retrospective pretest scores ( $M = 3.97$ ,  $SD = 0.84$ ),  $t(331) = 5.03$ ,  $p < .001$ , with a small effect size (*Cohen's d* = 0.28).

**Figure 1**

*Mean Problem-Solving Ratings at Pretest and Posttest*



*Note.*  $n = 332$ . Problem Solving was assessed in a single treatment group using a 5-point Likert-type scale (1 = Strongly disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly agree). \*\*\* $p < .001$ .

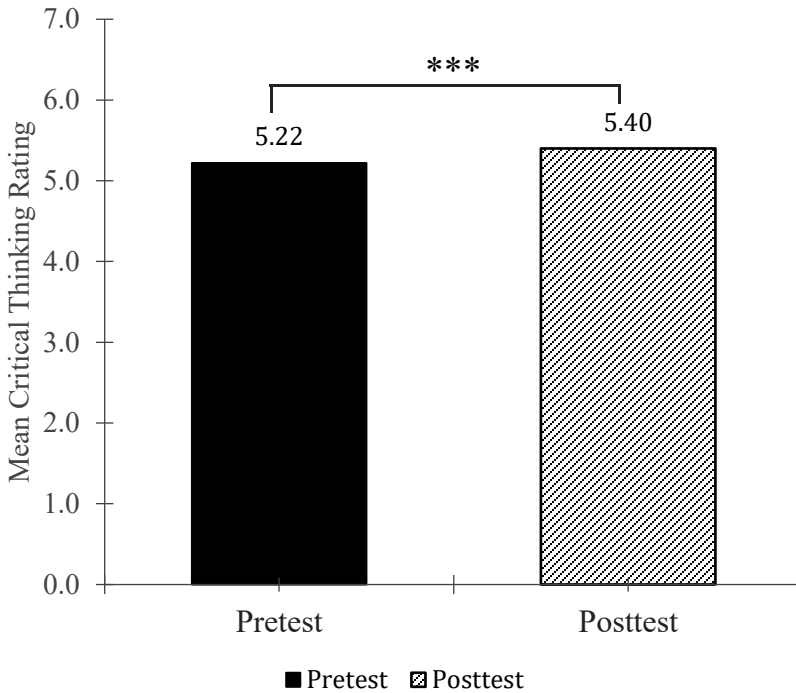
### **Critical Thinking**

*RQ2: Is participation in a PBL course associated with an increase in students' self-reported critical thinking skills?*

A paired-samples  $t$ -test indicated that PBL students reported a statistically significant increase in self-reported critical thinking scores at posttest ( $M = 5.40$ ,  $SD = 1.12$ ) compared to retrospective pretest scores ( $M = 5.22$ ,  $SD = 1.23$ ),  $t(329) = 4.17$ ,  $p < .001$ , with a small effect size (Cohen's  $d = 0.23$ ).

**Figure 2**

*Mean Critical Thinking Ratings at Pretest and Posttest*



*Note.*  $n = 330$ . Critical Thinking was assessed in a single treatment group using a 7-point Likert-type scale (1 = Not at all true of me; 7 = Very true of me). \*\*\* $p < .001$ .

## **Teamwork**

*RQ3: Is participation in a PBL course associated with an increase in students' self-reported teamwork skills?*

Self-reported ratings for teamwork items were excluded for one psychology section ( $n = 8$ ) as students worked independently and group work/collaboration was not a part of their course project experience.

A paired-samples  $t$ -test indicated that PBL students reported a statistically significant increase in self-reported teamwork skills at posttest ( $M = 4.35$ ,  $SD = 0.66$ ) compared to retrospective pretest scores ( $M = 4.20$ ,  $SD = 0.77$ ),  $t(321) = 5.43$ ,  $p < .001$ , with a small to moderate effect size (*Cohen's d* = 0.30).

## DISCUSSION

This study extends the PBL literature by demonstrating how project-based learning functions as a promising pedagogy within a Hispanic-Serving Institution, highlighting its role in supporting skill development among underrepresented STEM students within a scalable, programmatic intervention. Our study found that PBL was significantly associated with increase in three important self-reported skills: problem-solving, critical thinking, and teamwork. Students reported higher scores in all three self-reported skills from the start to the end of the course (all  $p < .001$ ), with effect sizes ranging from small to moderate (*Cohen's d* = 0.23 to 0.30). Taken together, these results support experiential learning theory, which suggests that students build understanding by doing, reflecting, and applying what they learn (Choshi, 2025). This may explain why even one PBL course was associated with increases in real, though modest, gains across all three skills. Notably, PBL was associated with increases in three different skills at once, rather than just one, suggesting it works as a broad tool that builds several skills together rather than strengthening one skill at a time (Bell, 2010). Students reported a small but statistically significant increase in problem-solving skills ( $\Delta M = 0.19$ ,  $d = 0.28$ ). PBL focuses on real-world problems, planning solutions, and reviewing them step by step, which matches how professionals work in STEM fields (Naseer et al., 2025) and may explain why students showed measurable gains. The effect size was modest, however, which may reflect the limited timeframe of this study. A single semester is a short amount of time, and PBL skills are meant to build through repeated practice (Choshi, 2025), so lasting problem-solving gains likely need more than one course. These results are especially important given the population served by this program. 60% are first-generation and come from low-income backgrounds. These characteristics were not measured in this study, but they are an important part of the context in which this program was implemented, and research shows these students often face more challenges in engagement and confidence (Evans et al., 2025).

Although the effect size is small for the critical thinking measure, the result is consistent across a large and diverse group of students ( $n = 332$ ) with high reliability ( $\alpha = .88$ ). This shows a real, though modest, increase in students' ability to analyze, evaluate, and reflect. Research shows that PBL supports critical thinking by asking students to work on complex, open-ended problems, evaluate evidence, and explain their ideas in groups (Busnawir et al., 2025). This is especially important for the STEM population, which includes many Hispanic students, who often face challenges not only in preparation but also in building confidence in higher-level thinking and academic identity (Murray et al., 2024). Critical thinking is often considered a skill that develops slowly, yet in this study it was associated with an increase through a low-cost intervention embedded in a

course rather than a separate program. Because PBL was already part of students' coursework, gains did not depend on extra time, staffing, or funding beyond what the course already required, making it an efficient and scalable approach to skill-building. The modest effect size may also reflect differences in implementation across courses and instructors, a pattern consistent with research showing that PBL delivery varies as faculty adopt and refine the approach over time (Evenddy et al., 2023; Wallace & Webb, 2016).

The growth in teamwork is important because PBL naturally supports teamwork skills when students work together on real projects (Sah et al., 2024). In this study, teamwork showed the largest effect of the three skills ( $d = 0.30$ ). One possible explanation is that students gained more direct, hands-on practice in teamwork through the shared responsibilities of the group project, while critical thinking and problem-solving may have developed more indirectly as students worked through the project. This interpretation is consistent with experiential learning theory's emphasis on learning through direct engagement (Choshi, 2025), though further research would be needed to confirm this pattern. These findings also support prior work showing that collaborating on real-world problems strengthens both technical and interpersonal skills, competencies critical for success in the workforce (Naseer et al., 2025).

This study looked at PBL in a Hispanic-Serving Institution and the results show that with proper support, PBL helps underrepresented students build important skills. PBL participation was associated with small but statistically significant increases in students' self-reported problem-solving, critical thinking, and teamwork skills in an HSI context. Beyond the skill gains themselves, these results speak to a broader goal: preparing Hispanic, low-income, and first-generation students for STEM careers. Many of these students face barriers that can make it harder to build these skills outside the classroom, such as work obligations and limited access to research or internship opportunities (Bangera & Brownell, 2014). Because PBL was built into required courses, it reached students regardless of outside access, making it a low-cost, scalable approach to workforce preparation. Future research should examine whether these gains carry over into career readiness, such as internship performance or persistence in STEM careers (Naseer et al., 2025).

## STUDY LIMITATIONS

This study has some limitations. First, this study used a retrospective pretest and posttest design, where students rated their skills after the course and then reflected on how they were at the beginning. This method helps reduce response bias compared to traditional pre-post surveys (McInerney et al., 2021). However, while the retrospective pretest-posttest design helped reduce some response-shift

bias, it is possible that students are also prone to memory errors, which could have resulted in inaccurate pretest self-report ratings.

Second, all data were self-reported, so this study measured students' perceptions of their skills rather than their actual performance. Adding an objective measure to complement the self-report surveys would improve study validity.

Third, the 65% response rate may cause selection bias, since students who had better experiences may have been more likely to respond.

Fourth, a lack of control group limits our ability to know with confidence that the observed changes were due to students' experiences in the course, and not just maturation that occurs over the semester. Consequently, this study cannot say definitively that the higher scores were only due to PBL.

Fifth, the study timeline occurred within four semesters, and therefore we are limited in our ability to understand longer-term effects of students' experiences in the PBL course, and we did not assess whether these perceived students' skill gains will last over time or continue in future courses.

Finally, the integration of additional measures such as focus group interviews would provide additional insight into students' growth in these skills over time.

This study still lacks robust longitudinal studies that follow students beyond a single course to see how PBL shapes later academic performance, readiness for professional practice, and durable habits of lifelong learning (Jaleniauskiene & Venckiene, 2025). Looking ahead, the field should close these gaps by prioritizing (1) robust longitudinal studies with adequate sample sizes to detect meaningful effects and appropriate comparison groups; (2) systematic collection and analysis of student-centered feedback to gauge implementation fidelity and learning impact; (3) institution-level examinations that are disaggregated by discipline and student demographics; and (4) stronger theorizing that clarifies how particular PBL design elements drive distinct outcomes (Simamora, 2024). By closing these gaps, we can build the evidence-based foundation needed to iteratively strengthen PBL implementation and draw more confident, generalizable conclusions about which design principles work best across varied higher education settings.

## **CONCLUSIONS AND IMPLICATIONS**

This study evaluates the use of PBL in undergraduate STEM courses and its association with skill development. Beyond measurable skill gains, the structure of PBL—centered on real-world inquiry, collaboration, and reflection—appears to foster deeper engagement, ownership of learning, and the development of transferable 21st-century skills essential for academic and professional success. The outcomes appear to depend on implementation. Effective PBL requires clearly defined learning objectives, alignment between instructional activities and assessment, and structured opportunities for collaboration, reflection, and

feedback. In the absence of these elements, the benefits of PBL may be reduced. Reported challenges related to time constraints, assessment complexity, and group dynamics further indicate that implementation is critical. Faculty preparation is therefore an important consideration, particularly in areas such as rubric design, facilitation of group work, and strategies to support accountability within teams. Embedding PBL within required coursework may also broaden access and ensure more consistent exposure. Extending PBL across multiple courses across all semesters could further support continuity in skill development and can broaden access and ensure that all students benefit from high-impact practices.

This study is limited by its reliance on self-reported measures and a single-institution sample. Longitudinal studies are needed to examine the durability of skill development over time and to assess how PBL influences long-term academic outcomes, career readiness, and persistence in STEM fields. The inclusion of performance-based assessments, such as direct evaluation of student work or standardized measures of critical thinking, would provide a more comprehensive account of learning outcomes. Further investigation of moderating factors, including student characteristics and specific design features of PBL, would help clarify the conditions under which this approach is most effective.

## AI TOOLS STATEMENT

The authors used generative AI tools (ChatGPT, OpenAI; Grammarly) to assist with language editing and formatting during the manuscript preparation process.

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