



## Implementation of STEM-PjBL Teaching Materials to Improve Student Learning Outcomes and Interest in Acid-Base Topics

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### Abstract

Although STEM-integrated Project-Based Learning (PjBL) has been widely examined for its effects on individual learning dimensions, no comparative study has simultaneously investigated its differential impact on both cognitive learning outcomes and affective learning interest using a two-class experimental design in Indonesian secondary chemistry education, particularly for the acid-base topic. Existing studies are further limited by single-variable focus, short-term self-report instruments, and a lack of multi-project STEM designs that integrate cross-disciplinary engineering and mathematical reasoning alongside scientific inquiry. This study addresses these gaps by implementing a STEM-PjBL e-module featuring three differentiated cross-disciplinary projects and comparing its effects against a conventional textbook-based PjBL class. A quasi-experimental pretest-posttest design was employed at SMAN 1 Panombeian Panei during the even semester of the 2025/2026 academic year, with a four-meeting intervention ( $2 \times 45$  minutes each). The sample comprised 60 students: 30 in Experimental Class 1 (STEM-PjBL e-module) and 30 in Experimental Class 2 (textbook + PjBL). Within the context of this study, Experimental Class 1 achieved a mean posttest of 80.50 (N-Gain = 0.521, moderate), while Experimental Class 2 achieved 66.00 (N-Gain = 0.266, low). Learning interest in Class 1 increased from 64% to 82% (+18%), compared to 61% to 77% (+16%) in Class 2. Independent Sample t-tests indicated significant differences in outcomes (sig. = 0.000) and interest (sig. = 0.033). Pearson correlation revealed a strong positive association ( $r = 0.789$ , sig. = 0.000). These findings suggest that, within this specific context, STEM-PjBL teaching materials with a multi-project design may provide greater pedagogical benefits than conventional textbook-based PjBL.

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## INTRODUCTION

Education in the era of the Industrial Revolution 4.0 and Society 5.0 demands that students develop 21st-century competencies including critical thinking, creativity, collaboration, and communication (4C). Science learning, particularly chemistry, is increasingly required to transition from abstract rote memorization toward contextual and applied pedagogical approaches that render subject matter relevant to students' everyday lives (Bybee, 2013). Learning success must be assessed

holistically, encompassing cognitive aspects (learning outcomes) and affective aspects (learning interest), as motivation and engagement are recognized as significant predictors of academic achievement (Schiefele, 2009).

However, chemistry instruction in many Indonesian secondary schools remains largely conventional, teacher-centered, and lecture-based. In abstract topics such as acid-base chemistry, students often exhibit passive learning behaviors, declining interest, and surface-level

understanding (Sari et al., 2021). This condition was empirically confirmed at SMAN 1 Panombeian Panei, where pre-study observations revealed approximately 82% of students failed to meet the minimum mastery criterion on acid-base topics. While the school had attempted Problem-Based Learning (PBL), its execution remained suboptimal due to incomplete instructional syntax and persistent teacher-centered delivery practices. The gap between curriculum expectations and classroom reality is further exacerbated by the limited availability of teaching materials that integrate innovative learning approaches capable of facilitating project-based learning in a contextual manner.

The integration of Science, Technology, Engineering, and Mathematics (STEM) approaches with Project Based Learning (PjBL) has emerged as a promising pedagogical solution. STEM-PjBL situates students as active constructors of knowledge through real-world projects, bridging abstract chemical concepts with tangible applications (Bybee, 2013; Han et al., 2015). This aligns with constructivism (Vygotsky, 1978), which posits that meaningful learning occurs when learners actively build knowledge through authentic experiences. Prior research demonstrates STEM-PjBL's efficacy in enhancing science literacy (Dibyantini et al., 2023; Amdayani et al., 2025), critical thinking (Rahmawati et al., 2021), learning outcomes (Amdayani et al., 2022; Alfitria, 2024), and motivational engagement Nugraha. (2024).

Despite this body of evidence, several critical gaps remain unaddressed in the existing literature. First, most prior STEM-PjBL studies examine either cognitive outcomes or affective dimensions in isolation; few studies employ a simultaneous, comparative measurement of both constructs within a single experimental design (Suciana et al., 2023). Second, while meta-analyses such as Cao et al. (2025) confirm positive aggregate STEM effects, they also highlight the methodological heterogeneity across primary studies — particularly the variability in STEM project complexity and the number of disciplinary integrations employed — making it difficult to attribute outcomes to specific design features. Third, the majority of existing studies implement a single integrated project, leaving unexamined whether multi-project designs with differentiated cross-disciplinary tasks produce superior

outcomes compared to standard single-project PjBL. Fourth, contradictory findings in the literature suggest that STEM-PjBL effects may be moderated by implementation fidelity, material design quality, and teacher competency (Han et al., 2015; Cao et al., 2025), necessitating context-specific empirical investigation.

This study therefore addresses these gaps by (1) simultaneously examining the differential effects of a multi-project STEM-PjBL e-module on both cognitive learning outcomes and affective learning interest, (2) employing a two-class comparative quasi-experimental design that isolates the specific contribution of STEM integration and multi-project e-module design from generic PjBL effects, and (3) providing indicator-level analysis of learning interest across five affective dimensions. The unique pedagogical contribution lies in the multi-project, cross-disciplinary design — integrating Engineering, Biology, and Mathematics within a single Chemistry topic — which extends beyond single-project implementations commonly reported in the literature. The study was conducted at SMAN 1 Panombeian Panei, Simalungun, North Sumatra, Indonesia

## METHOD

### Research Design and Participants

This study employed a quasi-experimental pretest-posttest two-group design. Research was conducted at SMAN 1 Panombeian Panei (Jl. Pendidikan No. 5, Marjandi, Kecamatan Panombeian Panei, Kabupaten Simalungun, North Sumatera) during the even semester of the 2025/2026 academic year. The population comprised all Grade XI IPA students. Purposive sampling was employed based on criteria: (1) both classes were taught by the same chemistry teacher; (2) the classes had comparable academic baseline scores; and (3) the school schedule allowed parallel implementation. Class XI IPA 2 ( $n = 30$ ) served as Experimental Class 1 and Class XI IPA 3 ( $n = 30$ ) as Experimental Class 2 (total  $N = 60$ ). It is acknowledged that the observed pretest mean difference (62.67 vs. 54.17) suggests possible baseline inequality; this is addressed in the data analysis section through N-Gain scores.

### Learning Implementation

Learning was implemented over four meetings ( $2 \times 45$  minutes each) for both classes. In Experimental Class 1, students were divided into

six groups with three differentiated STEM projects: (1) designing a floor cleaner from used cooking oil waste (Engineering × Chemistry), (2) designing a natural pH indicator from kitchen materials (Biology × Chemistry), and (3) proving acid-base product function quantitatively through pH calculation (Mathematics × Chemistry). All projects followed the six-stage PjBL syntax (Thomas, 2000): essential question → project design → scheduling → execution and monitoring → assessment → reflection. Meeting 1: pretest, initial interest questionnaire, essential question, project design; Meeting 2: group project execution; Meeting 3: project presentation, inter-group discussion, evaluation; Meeting 4: posttest and final interest questionnaire. Experimental Class 2 completed one project (natural acid-base indicator testing) using standard textbooks with the same PjBL syntax

### Research Instruments

Two instruments were used. (1) Cognitive test: An initial pool of 50 multiple-choice items was validated by three chemistry lecturers from FMIPA Universitas Negeri Medan. The validated instrument was piloted on 30 Grade XII IPA 3 students ( $r\text{-table} = 0.361$  at  $\alpha = 5\%$ ). Point-biserial correlation via SPSS 25 identified 24 valid items; the remaining 26 were excluded. Reliability of the 24 valid items yielded Cronbach's  $\alpha = 0.899$  (very high). Difficulty analysis yielded 12 easy and 12 moderate items; discriminating power analysis yielded 9 "very good" and 15 "good" items. The final 20 best items were selected for pretest and posttest. (2) Learning interest questionnaire: 25 Likert-scale items (4-point: strongly agree to strongly disagree) covering five indicators drawn from Schiefele (2009) and Hurlock (1978): (a) attention–degree of focus during learning; (b) relevance–perceived usefulness of material to daily life; (c) confidence–sense of self-efficacy in completing tasks; (d) satisfaction–positive emotional response from learning; (e) engagement–voluntary participation in learning activities.

### Ethical Considerations

This study was conducted with the written permission of SMAN 1 Panombeian Panei, Simalungun district, North Sumatra. Prior to data collection, all student participants and their parents or guardians were informed of the study's purpose, procedures, and voluntary nature of participation through an informed consent process coordinated by the class teacher.

Participation was voluntary, and students were assured that non-participation would not affect their academic standing. No personally identifying information is disclosed in this manuscript. All data were collected, stored, and reported in accordance with the ethical standards of educational research

### Data Analysis

Data were analyzed using SPSS 25. The Normalized Gain (N-Gain) formula (Hake, 1999) was employed to quantify cognitive improvement while controlling for pretest differences. Normality was assessed via Shapiro-Wilk; variance homogeneity via Levene's test. After confirming both assumptions, Independent Sample t-tests compared posttest and interest scores between classes. Pearson correlation examined the relationship between outcomes and interest. Qualitative data from six classroom observers provided triangulation support; however, as formal inter-rater reliability was not systematically computed, observational findings are reported as supplementary contextual evidence. Significance threshold:  $\alpha = 0.05$ . The pretest difference between classes was not controlled via ANCOVA; future research should employ ANCOVA or matched-pair designs to strengthen causal inference.

## RESULTS

### Instrument Validation

From 50 initial items, 24 were confirmed valid via point-biserial correlation ( $r > 0.361$ ). Reliability analysis yielded Cronbach's  $\alpha = 0.899$ , indicating very high internal consistency. Difficulty analysis showed 12 easy and 12 moderate items (no difficult items), ensuring the instrument measured the majority of students optimally. Discriminating power analysis yielded 9 "very good" and 15 "good" items. The final 20-item instrument provided comprehensive coverage of acid-base learning objectives.

### Learning Outcomes

Experimental Class 1 achieved a mean posttest of 80.50 compared to 66.00 in Experimental Class 2. The N-Gain for Class 1 was 0.521 (moderate), nearly double that of Class 2 (0.266, low), indicating substantially greater cognitive improvement. N-Gain values are particularly informative given the baseline difference (pretest means: 62.67 vs. 54.17), as N-Gain accounts for pretest performance in estimat-

ing relative learning improvement.

**Table 1. Student Pretest Posttest Averages**

| Score           | Experimental Class 1 | Experimental Class 2 |
|-----------------|----------------------|----------------------|
| <i>Pretest</i>  | 62.67                | 54.167               |
| <i>Posttest</i> | 80.5                 | 66                   |
| <b>N-Gain</b>   | 0.521(moderate)      | 0.266 (low)          |

### Learning Interest

Both classes showed improvements from similar baselines. Experimental Class 1 increased 18 percent from 64% to 82%; Class 2 from 61% to 77% (+16 percent). Indicator-level examination revealed that the relevance and satisfaction indicators showed the largest gains in Class 1, consistent with the cross-disciplinary nature of the STEM-PjBL design. The engagement indicator also improved notably, reflecting collaborative multi-project dynamics. In contrast, Class 2 showed its most pronounced gain in the attention indicator, while relevance and satisfaction gains were comparatively modest.

**Table 2. Average Initial and Final Student Learning Interest**

| Score            | Experimental Class 1 | Experimental Class 2 |
|------------------|----------------------|----------------------|
| Initial Interest | 64%                  | 61%                  |
| Final Interest   | 82%                  | 77%                  |
| Increase         | 18%                  | 16%                  |

### Data Analysis

Before hypothesis testing, prerequisite analyses were conducted, including normality and homogeneity tests. The Shapiro-Wilk normality test assessed whether the learning outcome and interest data were normally distributed; Levene's test verified homogeneity of variance across the two sample classes. After all prerequisites were met, hypothesis testing was conducted using the Independent Sample t-test to examine the significance of the effect of STEM-PjBL teaching materials on the dependent variables. All statistical analyses were performed using SPSS 25.

**Table 3. Normality Test of Learning Outcomes**

|                           | Class                | Shapiro Wilk Sig. | Note                |
|---------------------------|----------------------|-------------------|---------------------|
| Student Learning Outcomes | Experimental Class 1 | .147              | Normal Distribution |
|                           | Experimental Class 2 | .532              | Normal Distribution |

**Table 4. Normality Test of Learning Interest**

|                           | Class                | Shapiro Wilk Sig. | Note                |
|---------------------------|----------------------|-------------------|---------------------|
| Student Learning Interest | Experimental Class 1 | 0.427             | Normal Distribution |
|                           | Experimental Class 2 | 0.405             | Normal Distribution |

Based on the table 3 and Table 4, the Sig. value for the posttest of experimental class 1 was 0.147 and for experimental class 2 was 0.532. Since both Sig. values are greater than 0.05 ( $0.147 > 0.05$  and  $0.532 > 0.05$ ), it can be concluded that the student learning outcome data for both classes are normally distributed. The Sig. value for the

learning interest posttest in experimental class 1 was 0.427 and for experimental class 2 was 0.405. Since both Sig. values are greater than 0.05 ( $0.427 > 0.05$  and  $0.405 > 0.05$ ), it can be concluded that the student learning interest data for both classes are normally distributed. After this the homogeneity of the data is need to described.

**Table 5. Homogeneity Test of Learning Outcomes**

|                           | Class  | Levene's Test Sig. | Note        |
|---------------------------|--------|--------------------|-------------|
| Student Learning Outcomes | Mean   | .787               | Homogeneous |
|                           | Median | .753               | Homogeneous |

**Table 6. Homogeneity Test of Learning Interest**

|                           | Class  | Levene's Test Sig. | Note        |
|---------------------------|--------|--------------------|-------------|
| Student Learning Interest | Mean   | .596               | Homogeneous |
|                           | Median | .627               | Homogeneous |

Based on the table 5 and table 6, the *Sig.* value for the learning outcome data was 0.787. Since the *Sig.* value is greater than 0.05 ( $0.787 > 0.05$ ), it can be concluded that the student learning outcome data for experimental class 1 and experimental class 2 have Homogeneous or equal variances. The *Sig.* value for the learning interest data was 0.596. Since the *Sig.* value is greater than 0.05 ( $0.596 > 0.05$ ), it can be concluded that the student learning interest data for experimental class 1 and experimental class 2 have Homogeneous or equal variances.

**Table 7. Hypothesis Test**

| Hypothesis | Source            | Sig   | Decision    |
|------------|-------------------|-------|-------------|
| I          | Learning Outcomes | 0.000 | Ha Accepted |
| II         | Learning Interest | .033  | Ha Accepted |
| III        | Correlation       | .000  | Ha Accepted |

Hypothesis testing was conducted after data normality and homogeneity were confirmed. If the significance value (*Sig.*)  $< 0.05$ ,  $H_a$  was accepted. All three hypotheses were accepted: both learning outcomes (*sig.* = 0.000) and learning interest (*sig.* = 0.033) showed statistically significant differences between classes, and a significant positive correlation was found between outcomes and interest (*sig.* = 0.000).

All three hypotheses were accepted (*Sig.*  $< 0.05$ ). Statistical significance alone does not establish practical significance; the N-Gain comparison (0.521 vs. 0.266) provides additional evidence of educationally meaningful improvement in Class 1. Future studies should complement these findings with effect size measures such as Cohen's *d* and confidence intervals for more comprehensive statistical reporting.

## DISCUSSION

The findings provide converging quantitative evidence suggesting that STEM-PjBL e-module instruction may produce greater improvements in both learning outcomes and interest compared to conventional textbook-based PjBL, within the specific context of this study. Several theoretically grounded mechanisms may contribute to this pattern, though the quasi-experimental, non-randomized, and short-term nature warrants caution in causal interpretation.

First, the STEM-PjBL e-module operationalizes constructivist principles (Vygotsky, 1978; Piaget, 1970) by requiring students to actively

construct chemical knowledge through authentic, cross-disciplinary projects. The three differentiated projects each required simultaneous application of science principles, engineering design, mathematical reasoning, and practical technology — potentially creating a richer knowledge-building environment than the single project in Class 2, contributing to the higher N-Gain (0.521 vs. 0.266). This aligns with Dibyantini et al. (2023) and Amdayani et al. (2022). However, the observed differences may also partially reflect the novelty effect (Hawthorne effect), media attractiveness, or heightened teacher enthusiasm, rather than being exclusively attributable to the STEM-PjBL design (Han et al., 2015). Future studies employing extended intervention periods and active control conditions would help disentangle these alternatives.

Second, indicator-level analysis revealed that the relevance and satisfaction indicators showed the largest improvements in Class 1, consistent with the contextualization of learning within familiar household products and the tangible, outcome-visible nature of the multi-project cycle. This aligns theoretically with Ainley's (2006) situational interest theory. The engagement indicator was also notably elevated, reflecting collaborative multi-project dynamics. In contrast, Class 2 showed its most pronounced gain in attention, suggesting that even a single PjBL project captures student attention, but that deeper affective dimensions may require more multi-dimensional STEM integration. These findings corroborate Nugraha (2024) and Riskayanti (2023), while providing more nuanced indicator-level insight.

Third, the strong positive correlation ( $r = 0.789$ , *sig.* = 0.000) suggests a meaningful association between cognitive and affective dimensions. This aligns with Schiefele's (2009) interest-as-resource model and is corroborated by Wahyuningsih et al. (2021) and Simatupang (2021). However, given the cross-sectional interest measurement and quasi-experimental design, the direction of causality cannot be definitively established from these data.

Fourth, the two-class design — both using PjBL, differing only in teaching materials — provides a controlled basis for attributing differences to STEM integration and multi-project e-module design. The emergence of significant

differences despite both classes using PjBL is consistent with Suciana et al. (2023) and Cao et al. (2025), who identified STEM integration as the key moderator. Nonetheless, threats to validity remain: the Hawthorne effect, e-module media attractiveness, short intervention duration, self-report bias in interest measurement, purposive single-school sampling, and the absence of ANCOVA to control the pretest mean difference (62.67 vs. 54.17) all represent methodological limitations that weaken causal interpretation.

These limitations notwithstanding, the consistent pattern of results provides contextually meaningful preliminary evidence for the potential effectiveness of STEM-PjBL multi-project e-module approaches in Indonesian secondary chemistry education. Researchers are encouraged to replicate this design with larger multi-school samples, randomized assignment, ANCOVA-controlled analyses, extended intervention periods, and complementary behavioral measures..

Several limitations should be acknowledged. The sample was drawn from a single school, limiting generalizability. Learning interest was assessed solely through self-report questionnaires, introducing potential response bias; interest data therefore serve primarily as supplementary evidence to cognitive findings. The four-meeting intervention is relatively brief for observing long-term effects. Future research should employ larger multi-school samples, extend intervention periods, and incorporate objective behavioral measures of engagement alongside self-report instruments.

## CONCLUSION

Within the specific context of this quasi-experimental study at SMAN 1 Panombeian Panei, the STEM-PjBL e-module teaching materials demonstrated potential advantages over conventional textbook-based PjBL in enhancing both cognitive learning outcomes and affective learning interest in acid-base chemistry at the secondary school level. Experimental Class 1 achieved a mean posttest of 80.50 (N-Gain = 0.521, moderate), while Class 2 achieved 66.00 (N-Gain = 0.266, low). Learning interest improved by 18 percentage points in Class 1 (64% → 82%) versus 16 points in Class 2 (61% → 77%). Independent Sample t-tests confirmed significant

between-class differences (outcomes: sig. = 0.000; interest: sig. = 0.033). Pearson correlation established a strong positive association ( $r = 0.789$ , sig. = 0.000). Indicator-level analysis suggests that relevance and satisfaction were most distinctively enhanced by the multi-project STEM design.

The principal scientific contribution of this study lies in its simultaneous, comparative examination of both cognitive and affective learning dimensions using a design that isolates the specific contribution of STEM integration and multi-project e-module structure from generic PjBL effects. Findings should be interpreted with caution given the quasi-experimental design, purposive single-school sampling, short intervention duration, and potential alternative explanations such as novelty and Hawthorne effects. Future research should employ larger multi-school samples, randomized designs, ANCOVA-controlled analyses, extended intervention periods, and objective behavioral measures alongside self-report instruments.

## RECOMMENDATION

Chemistry teachers are encouraged to consider STEM-PjBL e-module teaching materials on acid-base topics as a contextually supported alternative to conventional instruction. For schools with limited internet access, the e-module may be adapted into hybrid print-digital formats. Future researchers should expand samples across multiple schools, employ randomized or ANCOVA-controlled designs, and investigate longitudinal effects on higher-order thinking skills, science literacy, and STEM career interest. The multi-project STEM-PjBL framework also warrants testing on other abstract chemistry topics such as thermochemistry, electrochemistry, and chemical equilibrium.

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