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ME-PjBL: A Project-Based Learning Model for Mathematical Entrepreneurship to Foster an Entrepreneurial Spirit

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ABSTRACT

The low level of entrepreneurial spirit among students remains a challenge for universities in producing graduates who not only possess academic competencies but are also capable of creating independent business opportunities. In mathematics education, teaching still tends to focus on mastering concepts and procedures; consequently, students' opportunities to relate mathematical concepts to real-world problem-solving and develop entrepreneurial competencies have not yet been optimized. This study aims to analyze changes in students' entrepreneurial spirit after taking a course using the ME-PjBL (Mathematical Entrepreneurship-Project-Based Learning) model, which integrates mathematical entrepreneurship with the Project-Based Learning model through the CREATE framework (Connect, Research, Explore, Apply, Transform, and Evaluate). The study employed a quantitative approach with a one-group pretest-posttest design. The research subjects consisted of 36 students in the Mathematics Education program. Data were collected using an entrepreneurial spirit questionnaire that included indicators of self-confidence, creativity, innovation, risk-taking, independence, cooperation and leadership, hard work, future orientation, application of mathematical concepts, and interest in entrepreneurship. Prior to use, the instrument met the criteria for content validity (Aiken's V = 0.86) and very high reliability (Cronbach's Alpha = 0.91). Data were analyzed using descriptive statistics and N-Gain calculations. The results showed that the average percentage of entrepreneurial spirit among students increased from 63.75% on the pretest to 89.69% on the posttest, representing an increase of 25.94% and an N-Gain value of 0.72, which falls into the high category. The indicator with the highest achievement was the application of mathematical concepts (91.67%), while the lowest achievement was in future orientation (88.19%); however, both fell into the "very good" category. These findings indicate that implementing the ME-PjBL model provides a learning experience that connects mathematical concepts with entrepreneurship-based projects and has the potential to foster students' entrepreneurial spirit.

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■ INTRODUCTION

Conventional mathematics teaching in higher education has been widely criticized for its limited capacity to cultivate entrepreneurial competencies, innovation, and authentic problem-solving skills. Traditional instructional approaches emphasize procedural knowledge, memorization, and algorithmic accuracy rather than creative thinking and applying mathematical concepts to complex real-world situations (Nilimaa, 2023; Raza & Reddy, 2021). Consequently, although higher education is expected to produce graduates who are adaptable, innovative, and entrepreneurial, many mathematics learning environments still provide limited opportunities for students to develop opportunity recognition, innovation, and entrepreneurial decision-making skills (Sidhu et al., 2018). Innovation, creativity, critical thinking, collaboration, communication, and technological literacy remain fundamental competencies required for graduates to respond to rapid technological change and global competition (Musa et al., 2025; Nurhayati et al., 2025; Zayyinah et al., 2022). Therefore, higher education institutions are increasingly

expected to prepare graduates who cannot only master disciplinary knowledge but also create knowledge-based business opportunities.

Mathematics is a subject taught at all levels of education. The level of difficulty in understanding, representation, conceptualization, and analysis in subjects related to geometry, arithmetic, calculus, and algebra presents students with alternatives tailored to their cognitive (Cung et al., 2019) and affective needs (Ascari et al., 2021). Despite its importance, mathematics instruction in higher education remains predominantly discipline-specific and frequently relies on decontextualized exercises that limit students' opportunities to apply mathematical reasoning in authentic entrepreneurial contexts (Antao & Morales, 2025). Furthermore, lecture-dominated classrooms often restrict inquiry, experimentation, collaboration, and interdisciplinary learning, thereby constraining the development of entrepreneurial competencies required in contemporary workplaces (Alimorad & Daneshfard, 2025; Raza & Reddy, 2021). Negative attitudes toward mathematics are often identified as the root cause of academic failure (Mazana et al., 2019). Nevertheless, when embedded in authentic learning experiences, mathematics has considerable potential to support entrepreneurial activities through data analysis, financial planning, optimization, forecasting, and evidence-based business decision-making.

According to data from the Central Statistics Agency (BPS), the open unemployment rate for university graduates in Indonesia in 2025 stood at 5.39%, indicating that higher education does not yet fully guarantee graduates' absorption into the workforce (BPS, 2025). The lack of entrepreneurial spirit among students remains a challenge for higher education institutions in Indonesia. Higher education institutions can no longer focus solely on developing academic competencies; they must also equip students to create business opportunities independently. Entrepreneurship is critical to government policy, as it is considered vital to driving economic and social prosperity (Mack & Honig, 2024).

One pedagogical approach that has received considerable attention in entrepreneurship education is Project-Based Learning (PBL). Rather than relying on conventional classroom instruction, PBL engages students in authentic, interdisciplinary projects that require opportunity recognition, feasibility analysis, product development, and collaborative problem-solving (de Campos et al., 2026; Naseer et al., 2025). Evidence consistently indicates that PBL strengthens entrepreneurial mindset, self-efficacy, creativity, critical thinking, collaboration, communication, and innovation by immersing students in experiential learning environments that simulate real-world entrepreneurial practice (García-Llamas et al., 2025; Rostami et al., 2024). The PjBL model is a learning approach that emphasizes students' active engagement in completing real-world projects through processes of investigation, collaboration, problem-solving, and the creation of specific products. According to Thomas, Project-Based Learning can enhance students' critical thinking, creativity, communication, and collaboration skills through authentic learning experiences (Husnita et al., 2025). Additionally, PjBL gives students opportunities to learn independently and in context through projects related to real-life situations. Project-Based Learning fosters critical thinking skills such as collaboration, critical thinking, and problem-solving, which are essential for academic success and future career readiness (Virtue & Hinnant-Crawford, 2019).

Although numerous studies have demonstrated that PBL enhances creativity, critical thinking, entrepreneurial mindset, and experiential learning, several limitations remain. Institutional barriers, assessment challenges, faculty readiness, and inconsistent implementation continue to constrain its effectiveness, while existing studies largely examine mathematical learning and entrepreneurship as separate educational domains (Mutanga, 2024; To & Truong, 2025). Consequently, current evidence provides limited understanding of how mathematical reasoning can be systematically integrated into entrepreneurship education through project-based learning environments. Several studies indicate that implementing the Project-Based Learning (PjBL) model can enhance students' creativity, critical thinking skills, and motivation to learn. This aligns with Sari & Anggraeni (2018), who reported that the PjBL model is effective in boosting student creativity. Additionally, other research indicates that PjBL is effective in developing 21st-century skills, including students' innovation and entrepreneurship capabilities.

Previous research has demonstrated that Project-Based Learning can enhance students' creativity, critical thinking, entrepreneurial mindset, and experiential learning (Kujala et al., 2022; Naseer et al., 2025; Nurhayati & Handayani, 2025; Rostami et al., 2024). However, empirical studies that explicitly integrate mathematical reasoning with

entrepreneurship through a structured, project-based instructional model remain scarce (Melnik et al., 2025; Pandey et al., 2025). Furthermore, existing entrepreneurship education research primarily focuses on entrepreneurial intention, innovation, or venture creation, with relatively little attention devoted to instructional models that deliberately embed mathematical reasoning into entrepreneurial learning activities (Kujala et al., 2022; Yulastri & Ferdian, 2023). Therefore, the ME-PjBL model is proposed as an instructional innovation that integrates mathematical competencies with entrepreneurial competencies through the CREATE framework (Connect, Research, Explore, Apply, Transform, and Evaluate), enabling students to engage in authentic, mathematics-based entrepreneurial projects.ME-PjBL places students at the center of the learning process through stages that include identifying contextual business problems, designing business projects, conducting mathematical investigations and analyses, developing products or services, and presenting the results of entrepreneurial projects. Through this process, students are expected to cultivate an entrepreneurial spirit, including creativity, innovation, independence, decision-making skills, leadership, and the courage to take risks. The development of the ME-PjBL model is also based on the need for more contextual and applied learning in higher education. Learning environments that remain predominantly teacher-centered continue to provide limited opportunities for students to engage in authentic entrepreneurial problem-solving and interdisciplinary knowledge integration (Ademola et al., 2023; Kurniawan et al., 2026). Therefore, an instructional model that explicitly integrates mathematical reasoning with entrepreneurial project development is needed to bridge this pedagogical gap.

Based on this gap, this study aims to examine changes in students' entrepreneurial spirit after implementing the ME-PjBL (Mathematical Entrepreneurship–Project-Based Learning) model. Specifically, this study addresses the following research questions: (1) How does students' entrepreneurial spirit change after participating in ME-PjBL? (2) Which dimensions of entrepreneurial spirit demonstrate the greatest improvement following the implementation of ME-PjBL? Furthermore, (3) To what extent does the CREATE framework facilitate the integration of mathematical reasoning and entrepreneurship in project-based learning? This study contributes to the literature by proposing an interdisciplinary instructional model that systematically integrates mathematical reasoning and entrepreneurship within project-based learning to support more contextual, collaborative, and authentic learning experiences in higher education.

■ METHOD

Research Design

This study employed a descriptive quantitative approach using a pre-experimental design, specifically a One-Group Pretest-Posttest Design. This design was used to determine changes in students' entrepreneurial spirit before and after taking a course using the ME-PjBL (Mathematical Entrepreneurship-Project-Based Learning) model. A pre-experimental design was selected because the ME-PjBL model was being implemented for the first time within an existing Mathematical Entrepreneurship course, making it impractical to include a comparison group within the institutional setting. This design provided preliminary evidence regarding changes in students' entrepreneurial spirit following the intervention while serving as an initial evaluation of the instructional model. However, because no control group was included, interpret the findings with caution due to potential threats to internal validity, including maturation, testing effects, and history. Consequently, the study identifies associations between participation in the ME-PjBL model and changes in entrepreneurial spirit rather than establishing causal relationships. Students completed an entrepreneurial spirit questionnaire before implementing the ME-PjBL model and again after completing the fourteen-session intervention, and the resulting scores were compared to examine changes across the intervention period.

Research Participants

The subjects of this study were 36 students in the Mathematics Education Program enrolled in the Mathematical Entrepreneurship course. A total sampling approach was employed because all students enrolled in the course participated in the study. The participants were active undergraduate students who had completed prerequisite mathematics education courses before enrolling in the Mathematical Entrepreneurship course, ensuring comparable academic preparedness for the intervention. Participants were recruited based on the following inclusion criteria: (1) official enrollment in the Mathematical Entrepreneurship course, (2) attendance throughout the fourteen-session implementation of the ME-PjBL model, and (3) completion of

Table 1. Indicators of the Student Entrepreneurial Spirit Questionnaire and Number of Items

No.	Indicator	Number of Items
1.	Self-Confidence	4
2.	Creativity	4
3.	Innovation	4
4.	The courage to take risks	4
5.	Independence	4
6.	Collaboration and leadership	4
7.	Hard Work	4
8.	Future-oriented	4
9.	Applications of Mathematical Concepts	4
10.	Interest in entrepreneurship	4
	Total	**40**

both the pretest and posttest questionnaires. Students who did not complete either questionnaire or withdrew from the course during the study period were excluded from the analysis.

Research Instruments

The research instrument consisted of a questionnaire on students' entrepreneurial spirit, which is based on ten indicators: self-confidence, creativity, innovation, risk-taking, independence, teamwork and leadership, hard work, future orientation, application of mathematical concepts, and interest in entrepreneurship. The questionnaire was self-developed based on established entrepreneurship education literature and entrepreneurial competency frameworks to capture students' perceptions of entrepreneurial characteristics relevant to mathematics learning. Each indicator was represented by four statements measured using a four-point Likert scale ranging from 1 (strongly disagree) to 4 (strongly agree). Higher scores indicate stronger perceived entrepreneurial spirit. Before the main analysis, questionnaire scores were converted into percentages and interpreted using predefined score categories to facilitate comparison across entrepreneurial dimensions. The following are the indicators of the Student Entrepreneurial Spirit Instrument along with their items.

Before use, the research instrument was validated by three experts: an expert in mathematics education, an expert in project-based learning, and an expert in entrepreneurship. The content validity test using Aiken's V index showed an average value of 0.86, which falls into the "highly valid" category. Furthermore, the reliability test using Cronbach's Alpha coefficient yielded a value of 0.91, indicating that the instrument has a very high level of reliability.

DataAnalysis

Research data were collected through questionnaires administered before and after the implementation of the ME-PjBL model, which was conducted over 14 sessions. Data analysis consisted of both descriptive and inferential statistics. Descriptive statistics, including percentages, means, standard deviations, and normalized gain (N-Gain) scores, were calculated to describe changes in entrepreneurial spirit across the ten indicators. Prior to hypothesis testing, the normality of the pretest and posttest scores should be examined using the Shapiro–Wilk test. If the data satisfy the assumption of normality, a paired-samples t-test is conducted to determine whether changes between the pretest and posttest are statistically significant. Otherwise, the Wilcoxon signed-rank test is employed as a non-parametric alternative. Statistical significance is determined at the 0.05 level. The results of the survey are categorized as follows:

Table 2. Criteria for survey results (Percentage)

Percentage	Category
81%–100%	Very Good
61%–80%	Good
41%–60%	Fairly
21%–40%	Bad
0%–20%	Very bad

Next, the improvement in students' entrepreneurial spirit was analyzed using the N-Gain score to determine the effectiveness of implementing the ME-PjBL model.

Table 3. N-gain category

N-Gain	Category
>0.70	High
>0.30-0.70	Moderate
<0.30	Low

EthicalConsiderations

This study was conducted in accordance with research ethics principles, including respect for participants' rights, data

confidentiality, and voluntary participation. Before data collection began, all students received an explanation regarding the research objectives, procedures, and benefits, as well as their right to refuse or withdraw from the study at any time without academic consequences. Informed consent was obtained from all respondents; confidentiality was maintained through the use of codes in the research data, and all information obtained was used solely for academic purposes and the preparation of the research report.

■ RESULT AND DISCUSSION

This study aimed to determine students' entrepreneurial spirit profile after taking a course using the ME-PjBL (Mathematical Entrepreneurship based on Project-Based Learning) model. Data were collected through a questionnaire distributed to 36 students who had taken the course for one semester. The students' entrepreneurial spirit was measured based on 10 indicators of entrepreneurial spirit, namely: 1) Self-confidence; 2) Creativity; 3) Innovation; 4) Risk-taking; 5) Independence; 6) Cooperation and leadership; 7) Hard work; 8) Future orientation; 9) Application of Mathematical Concepts; 10) Interest in Entrepreneurship. To provide a more comprehensive evaluation of changes following the intervention, descriptive statistics, normalized gain (N-Gain), normality testing, paired-samples t-test analysis, and graphical visualizations were employed.

The average N-Gain score of 0.72 indicates a substantial improvement in students' entrepreneurial spirit following participation in the ME-PjBL model. To determine whether this improvement was statistically significant, the difference scores were first examined using the Shapiro–Wilk normality test. The results indicated that the assumption of normality was satisfied ($W = 0.972$, $p = .475$). Accordingly, a paired-samples t-test revealed a statistically significant increase in entrepreneurial spirit scores from pretest to posttest, $t(35) = 54.67$, $p < .001$ (Table 5). These findings indicate that students reported significantly higher entrepreneurial spirit scores following participation in the ME-PjBL model. Table 4 presents a descriptive comparison of pretest and posttest scores across entrepreneurial spirit indicators.

Based on Table 4, all entrepreneurial spirit indicators showed higher posttest scores than pretest scores following participation in the ME-PjBL model. The largest increase was in the risk-taking indicator (31.60%), while the collaboration and leadership indicator showed the smallest increase (19.44%). Overall, students' entrepreneurial spirit scores increased by an average of 25.94 percentage points. Figure 1 illustrates the distribution of individual pretest and posttest scores. Nearly all participants are positioned above the diagonal reference line ($y = x$), indicating that posttest scores exceeded pretest scores for most students. Although the magnitude of improvement varied among participants, the scatter plot shows that improvement occurred consistently across individual students rather than being driven solely by changes in the group mean. Figure 2 complements these findings by presenting the average pretest and posttest scores for each entrepreneurial spirit indicator, allowing clearer identification of the dimensions that improved most following participation in the ME-PjBL model.

Table 4. Pretest-posttest comparison

No.	Indicator	Pretest (%)	Posttest (%)	Difference (%)	N-Gain
1	Self Confident	59.38	89.24	29.86	0.74
2	Creativity	59.72	89.24	29.52	0.73
3	Innovation	63.54	89.58	26.04	0.71
4	Risk Taking	56.25	87.85	31.60	0.72
5	Independence	71.18	91.32	20.14	0.70
6	Collaboration and Leadership	71.53	90.97	19.44	0.68
7	Hardwork	69.44	91.32	21.88	0.72
8	Future Orientation	56.60	88.19	31.59	0.73
9	Application of Mathematical Concepts	71.53	91.67	20.14	0.71
10	Interest in Entrepreneurship	58.33	88.54	30.21	0.72
	Avarage	63.75	89.69	25.94	0.72

Table 5. Results of the Shapiro–Wilk test and paired-samples

Analysis	Test Statistic	p-value	Interpretation
Shapiro–Wilk normality test	W = 0.972	0.475	The difference scores were normally distributed (p > .05).
Paired-samples t-test	*t* (35) = 54.67	< .001	A statistically significant increase was observed between the pretest and posttest entrepreneurial spirit scores.

Figure 1 presents the distribution of individual pretest and posttest entrepreneurial spirit scores. All participants were positioned above the diagonal reference line ($y=x$), indicating that each student obtained a higher posttest score than the corresponding pretest score following participation in the ME-PjBL model. Although the magnitude of improvement varied among students, the scatter plot demonstrates that the increase was consistently observed at the individual level rather than being driven solely by changes in the group mean.

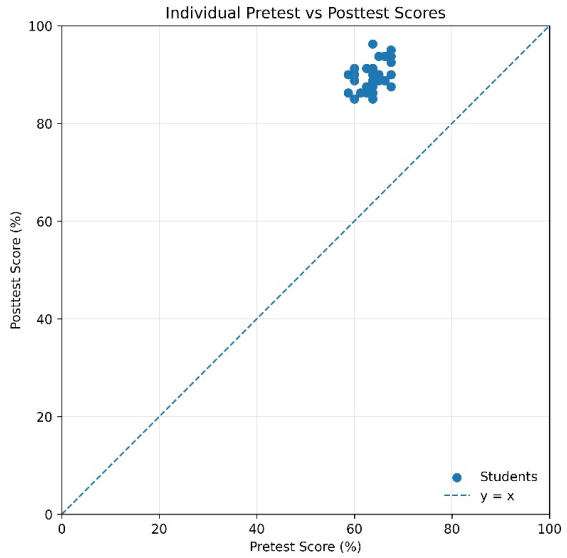

Figure 1. Scatter plot of individual pretest and posttest entrepreneurial spirit scores

Figure 2 compares the average pretest and posttest scores across the ten entrepreneurial spirit indicators. All indicators demonstrated higher posttest scores following participation in the ME-PjBL model. The largest increase was observed in risk-taking, followed closely by future orientation and interest in entrepreneurship, whereas collaboration and leadership showed the smallest increase. The application of mathematical concepts achieved the highest posttest score. This visualization complements the numerical results by helping readers more clearly identify which dimensions changed the most following the intervention.

According to Table 6, the implementation of the ME-PjBL model achieved an average of 95%, which falls into the "very good" category. The "Explore" aspect received the highest percentage (97%), while the "Research" aspect received the lowest percentage (93%). These findings indicate that all stages of the CREATE framework were implemented consistently throughout the course, providing students with authentic opportunities to engage in contextual problem identification, mathematical investigation, entrepreneurial project development, product innovation, and reflective evaluation. The consistently high implementation scores also suggest that the observed changes in entrepreneurial spirit occurred within a learning environment where the instructional procedures were implemented as intended.

ME-PjBL Can Foster Entrepreneurial Spirit Among Students

The research results show that the average level of entrepreneurial spirit among students increased from 63.75% in the pretest to 89.69% in the posttest. The paired-samples t-test indicates that the observed improvement is unlikely to be attributable to random variation alone. However, because the study employed a one-group pretest–posttest design without a comparison group, the findings should be interpreted as evidence of statistically significant improvement following participation in the ME-PjBL model rather than definitive proof of causal effectiveness. These findings also suggest that participation in the ME-PjBL (Mathematical Entrepreneurship–Project-Based Learning) model was associated with higher levels of students' entrepreneurial spirit following the intervention. Rather than relying solely on conceptual mastery, integrating mathematics learning with entrepreneurship-oriented projects may provide more authentic and meaningful learning experiences that encourage students to connect mathematical reasoning with real-world entrepreneurial challenges.

This success is closely tied to the CREATE framework, which is a key characteristic of the ME-PjBL model. In the

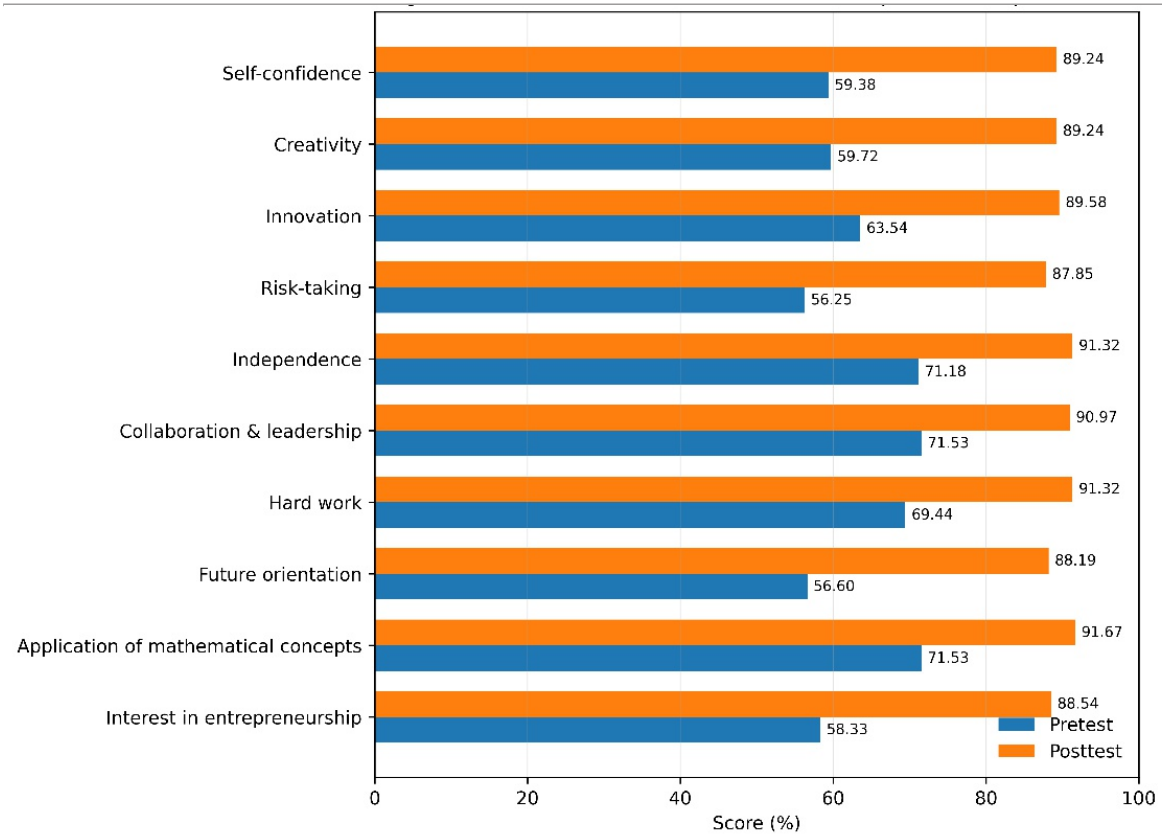

Figure 2. Comparison of average pretest and posttest scores across entrepreneurial spirit indicators

Connect phase, students are presented with various real-world problems related to business opportunities, encouraging them to identify market needs and develop mathematics-based solutions. The Research and Explore phases provide students with the opportunity to explore mathematical concepts relevant to the projects they are developing. Next, in the Apply stage, students implement business ideas as products or services with economic value. The Transform and Evaluate stages encourage students to innovate and reflect on the results of the projects they have carried out. From a cognitive perspective, these sequential learning activities encourage students to actively construct knowledge by applying mathematical concepts to authentic entrepreneurial problems rather than simply recalling procedures. Such learning-by-doing experiences strengthen opportunity recognition, critical thinking, decision-making, and problem-solving while promoting the integration of knowledge across multiple disciplines (Donoso et al., 2025; Makry, 2026; Nurhayati et al., 2024).

Continuous reflection during the Transform and Evaluate stages further supports metacognitive development by enabling students to evaluate, refine, and improve their ideas through iterative feedback (Callewaert et al., 2021; Masli et al., 2026). From a motivational perspective, the CREATE framework may also explain the observed

Table 6. Percentage of implementation of the ME-PjBL model

Aspect	Percentage (%)	Category
Connect (Real Problems)	95%	Very good
Research (Concept Exploration)	93%	Very good
Explore (Project Design)	97%	Very good
Apply (Project Implementation)	94%	Very good
Transform (Product Innovation)	96%	Very good
Evaluate (Reflection and Evaluation)	95%	Very good
Average	95%	Very good

improvement because students were required to complete meaningful entrepreneurial projects that fostered ownership, autonomy, and sustained engagement throughout the learning process. Successfully designing, implementing, and presenting project outcomes may have strengthened students' confidence and entrepreneurial self-efficacy, while collaborative learning created opportunities to exchange ideas, receive peer support, and develop the confidence to take calculated risks (Davletova et al., 2025; Noor & Nurhayati, 2024; Saputro et al., 2026). Experientially, ME-PjBL bridges mathematical theory and entrepreneurial practice by engaging students in authentic project development that resembles real entrepreneurial activities. Through teamwork, project implementation, and iterative improvement, students experience how mathematical reasoning can support business planning, innovation, and decision-making. Such authentic experiences have been widely recognized as important mechanisms for strengthening entrepreneurial competencies, communication, collaboration, leadership, adaptability, and creative problem-solving (Chauhan et al., 2025; Rodriguez & Lieber, 2020). Therefore, the improvement observed in this study may be interpreted not merely as a consequence of project completion, but as the result of interconnected cognitive, motivational, and experiential learning processes facilitated through the CREATE framework.

These findings are consistent with Hagvall et al. (2020), who emphasized that entrepreneurship education becomes more meaningful when students engage in authentic, reflective, and experience-based learning activities. However, the findings should be interpreted within the context of the present pre-experimental design. Because no comparison group was included, the observed improvement indicates an association between participation in ME-PjBL and increased entrepreneurial spirit rather than definitive evidence of causal effectiveness. Future studies employing quasi-experimental or experimental designs across multiple educational contexts are therefore needed to further validate the effectiveness and generalizability of the ME-PjBL model.

Enhancing Creativity and Innovation through Projects

The research results show that the creativity indicator increased from 59.72% on the pretest to 89.24% on the posttest, while the innovation indicator increased from 63.54% to 89.58%. These findings suggest that participation in the ME-PjBL model was associated with higher levels of students' perceived creativity and innovation following the intervention. Rather than merely completing projects, students were encouraged to identify authentic entrepreneurial problems, generate multiple solution alternatives, and iteratively refine their ideas throughout the CREATE learning cycle. Creativity and innovation increased because students were given the freedom to design and develop entrepreneurial projects aligned with each group's interests and potential. The products students produced included concrete and web-based learning media, math tutoring services, educational e-books, textbooks, and other educational products with market value.

Figure 3 presents representative examples of student-developed entrepreneurial products. These examples illustrate how students translated mathematical concepts into tangible educational products, including an interactive mathematics learning media (TRANSMATH) and a digital educational service platform (BESTEACH). The visual evidence demonstrates that the entrepreneurial projects extended beyond conceptual planning to the development of prototypes and promotional materials with potential educational and commercial value. This autonomy encouraged divergent thinking and enabled students to integrate mathematical knowledge with entrepreneurial contexts, thereby stimulating creativity, adaptability, and innovative thinking through authentic interdisciplinary learning experiences (Nurhayati, 2020; Nweke et al., 2025; Prastowo et al., 2025). Furthermore, continuous reflection and iterative feedback during project development supported metacognitive processes that allowed students to evaluate and refine their ideas, an important mechanism underlying entrepreneurial creativity (Callewaert et al., 2021). The freedom to generate project ideas encouraged students to think divergently, explore various alternative solutions, and produce innovations that differed from one group to another. From a motivational perspective, meaningful project ownership may also have strengthened students' intrinsic motivation, responsibility, and willingness to experiment with innovative solutions. At the same time, collaborative learning created opportunities to exchange ideas and receive constructive peer feedback (Zhang et al., 2024). Consequently, the ME-PjBL model appears to support not only academic learning but also the development of entrepreneurial creativity through authentic project experiences that produce outputs with potential practical and economic value This

finding aligns with the results of a study by Sari and Anggraeni ((2018)), as well as more recent evidence demonstrating that authentic project-based learning enhances creativity, innovation, and entrepreneurial competencies through active engagement, interdisciplinary collaboration, and experiential learning (Issa & Khataibeh, 2021; Rodriguez & Lieber, 2020).

Figure 3. Examples of student entrepreneurship products developed through the me-pjbl model

The representative products shown in Figure 3 further support the qualitative interpretation of the findings by providing visual evidence that students successfully transformed mathematical ideas into authentic entrepreneurial products. The diversity of the developed products also reflects the ME-PjBL model's flexibility in accommodating different interests, business ideas, and creative approaches while maintaining the integration of mathematical reasoning and entrepreneurship.

Students' Independence and Self-Confidence Are Growing

The confidence indicator increased from 59.38% to 89.24%, while the independence indicator increased from 71.18% to 91.32%. These findings indicate that students reported higher levels of perceived self-confidence and independence following participation in the ME-PjBL model. The CREATE framework may have contributed to these improvements by positioning students as active decision-makers who were responsible for planning, implementing, monitoring, and evaluating entrepreneurial projects throughout the learning process. During project implementation, students were fully responsible for planning, executing, managing, and evaluating the projects they developed. These conditions required students to make decisions independently, manage group work strategies, overcome obstacles, and take responsibility for the results. These authentic responsibilities align with experiential learning principles, where autonomy and direct engagement promote self-directed learning and strengthen students' confidence in managing complex tasks (Atsu et al., 2022; Ramdani et al., 2025).

In addition, in-class project presentations allow students to communicate ideas, defend their arguments, and receive feedback from instructors and peers. Iterative feedback from lecturers and peers, along with collaborative problem-solving, may have strengthened students' perceived competence, entrepreneurial self-efficacy, communication skills, and willingness to take calculated risks (Davletova et al., 2025; Saputro et al., 2026). Collaborative learning environments also foster social support and shared responsibility, which contribute to developing confidence and independent learning behaviors. These experiences gradually build students' confidence in their abilities. Accordingly, the observed improvement may reflect the combined influence of cognitive engagement, motivational support, and authentic experiential learning embedded within the CREATE framework rather than project completion alone. This finding aligns with the results of a study by Virtue and Hinnat-Crawford (2019). Recent studies further support this, indicating that authentic project-based learning strengthens entrepreneurial self-efficacy, communication, leadership, and learner autonomy through meaningful real-world engagement (Asyari et al., 2024; Rodriguez & Lieber, 2020).

The Integration of Mathematics and Entrepreneurship as a Strength of ME-PjBL

One of the most significant findings of this study is the high score on the indicator of applying mathematical concepts, which increased from 71.53% to 91.67% and was the highest among all indicators. These findings suggest that students reported stronger perceptions of their ability to apply mathematical concepts within entrepreneurial contexts after participating in the ME-PjBL model. Because this indicator was measured using a self-report questionnaire, the results should be interpreted as students' perceived capability rather than direct evidence of their actual mathematical performance in entrepreneurial practice. Through the projects they developed, students reported applying various mathematical concepts such as cost-benefit analysis, pricing strategies, profit optimization, data processing, sales forecasting, and mathematical modeling to support business decision-making. Embedding these concepts within authentic entrepreneurial projects may

have encouraged students to recognize the practical relevance of mathematics for solving business-related problems, thereby facilitating knowledge transfer from theoretical learning to applied contexts.

From a cognitive perspective, such authentic problem-solving activities strengthen critical thinking, opportunity recognition, and analytical decision-making by requiring students to integrate mathematical reasoning with entrepreneurial considerations (Donoso et al., 2025; Yulianti, 2024). The interdisciplinary nature of project development further promotes creativity and innovation by encouraging students to connect mathematical knowledge with business planning and product development (Nweke et al., 2025). Consequently, students may increasingly perceive mathematics as a practical tool that supports entrepreneurial decision-making rather than solely as an abstract academic discipline. This finding represents both a strength and a novelty of the ME-PjBL model. Unlike conventional Project-Based Learning models, which focus on project completion, ME-PjBL deliberately embeds mathematical reasoning throughout the entrepreneurial process, beginning with opportunity identification, continuing through mathematical analysis and business planning, and culminating in product development and reflective evaluation. This structured integration aligns with recent calls for interdisciplinary instructional models that simultaneously support analytical reasoning and entrepreneurial competence through authentic learning experiences (Rodriguez & Lieber, 2020). Nevertheless, successful implementation of such integrated learning depends on institutional support, educator expertise, and adequate mentoring, as previous studies show that project-based entrepreneurship learning is strongly influenced by contextual and organizational conditions (Awashreh, 2025; Owusu-Acheampong et al., 2025; Rakhimova et al., 2025).

Entrepreneurial Reflection Shapes Students' Future Orientation

The future orientation indicator increased from 56.60% on the pretest to 88.19% on the posttest, while interest in entrepreneurship increased from 58.33% to 88.54%. These findings suggest that participation in the ME-PjBL model was associated with more positive perceptions of future entrepreneurial opportunities and stronger interest in entrepreneurship. The Transform and Evaluate stages appear to play an important role by encouraging students to critically examine the strengths and limitations of their projects while considering opportunities for future improvement and business development. During these stages, students reflect on the successes and weaknesses of the projects they have developed and then formulate strategies for future business development. Reflection and iterative feedback constitute essential metacognitive processes that help students evaluate their learning, refine entrepreneurial ideas, and continuously improve proposed solutions (Masli et al., 2026).

This reflective practice aligns with experiential learning principles, which emphasize that entrepreneurial competence develops through repeated cycles of action, evaluation, and refinement rather than through theoretical instruction alone (Atsu et al., 2022). Reflection activities help students understand their business potential and the opportunities to develop their projects into sustainable businesses. From a motivational perspective, completing entrepreneurial projects and receiving constructive feedback may strengthen students' confidence, entrepreneurial self-efficacy, and willingness to pursue future entrepreneurial activities (Davletova et al., 2025). Collaborative project experiences also cultivate communication, leadership, and shared responsibility, reinforcing students' readiness to engage in future entrepreneurial challenges (Asyari et al., 2024). Through this experience, students not only gain knowledge about entrepreneurship but also build confidence that the ideas and products they create can become real businesses. Nevertheless, previous studies indicate that the long-term development of entrepreneurial orientation depends not only on project-based learning itself but also on broader institutional and contextual factors, including mentoring quality, university–industry collaboration, institutional commitment, and access to entrepreneurial ecosystems (Ademola et al., 2023; Owusu-Acheampong et al., 2025). Therefore, while the present findings demonstrate encouraging improvements in students' perceptions of future entrepreneurial orientation, sustained entrepreneurial development will likely require continued institutional support beyond the duration of a single course.

■ CONCLUSION

Based on the research results, implementing the ME-PjBL model was followed by an increase in the entrepreneurial spirit scores of Mathematics Education students. The results showed that the average percentage of students' entrepreneurial spirit

increased from 63.75% on the pretest to 89.69% on the posttest, falling into the "very good" category. This increase was evident across all indicators: self-confidence, creativity, innovation, risk-taking, independence, cooperation and leadership, hard work, future orientation, application of mathematical concepts, and interest in entrepreneurship. Given the pre-experimental one-group pretest–posttest design, these findings should be interpreted as evidence of positive changes observed following participation in the ME-PjBL model rather than definitive evidence of causal effectiveness.

The findings indicate that integrating Mathematical Entrepreneurship with Project-Based Learning through the CREATE framework (Connect, Research, Explore, Apply, Transform, and Evaluate) may provide students with a more contextual and authentic learning experience. Through this series of activities, students can relate mathematical concepts to the development of entrepreneurship-related projects, which may contribute to the development of entrepreneurial character and interest. The findings also suggest that embedding mathematical reasoning within authentic entrepreneurial projects has the potential to strengthen students' perceived entrepreneurial competencies while encouraging the application of mathematical knowledge in real-world contexts. Nevertheless, future studies employing quasi-experimental or experimental designs with comparison groups, larger and more diverse samples, and longitudinal follow-up are needed to establish the effectiveness and broader applicability of the ME-PjBL model across different higher education contexts.

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