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Effect of STEM-PBL advanced mathematics course on engineering students' problem-solving ability in higher vocational college

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This study explores the effect of STEM-problem based learning (STEM-PBL) advanced Mathematics on engineering students' problem-solving ability (PSA) in higher vocational colleges. Grounded in STEM-PBL and student's PSA framework, the study integrates mobile and digital technologies, including GeoGebra and MATLAB, into a context-rich instructional design. A quasi-experimental design was employed involving 83 students, with 42 assigned to the experimental group (EG) and 41 to the control group (CG). Quantitative data were collected through pre-test, post-test, and analyzed using SPSS. The results showed that STEM-PBL instruction significantly improved students' PSA. These findings suggest that incorporating STEM-PBL content and digital tools into mathematics education is essential for developing basic PSA among engineering students. This study provides practical guidance for designing effective, equitable, and skill-oriented STEM courses in vocational education.

KEYWORDS

STEM-PBL-based advanced mathematics, engineering students, problem-solving ability, quasi-experimental design, vocational education

1 Introduction

The current economic and social development, the demand for skilled personnel is also increasing. Many countries attach importance to higher vocational colleges and support is increasing. Data from Ministry of Education of the People's Republic of China shown that at the higher education stage in China, there are 1,545 higher vocational colleges (including vocational undergraduates), with an enrollment of approximately 4.83 million students in 2024, exceeding the enrollment of ordinary undergraduates for five consecutive years. According to the talent training goals of higher vocational colleges issued by the Ministry of Education of the People's Republic of China: Higher vocational colleges are a vital part of my country's higher education, cultivating students into high-quality technical application talents who combine theory and practice. Advanced mathematics courses are required general education courses for engineering majors (Song, 2021) and play a pivotal role in talent cultivation (Li and Li, 2023; Zhang et al., 2023). Importantly, the majority of college courses call for a mathematical education, and mastery of the topic is a key indicator of a student's aptitude across a range of subjects (Boaler, 2022; Darmayanti et al., 2022). However, students often think that mathematics is difficult and do not know how to combine it with practice, resulting in unsatisfactory learning results.

Due to STEM education in China is still in its infancy, there is little higher education on STEM teaching, and even less research on students' PSA (Ma, 2021). According to research, STEM education can provide students with more career opportunities, so STEM education is strongly supported (Rezayat and Sheu, 2020; Zhong et al., 2022). However, due to the interdisciplinary nature of STEM projects and the current typical school structure, teachers face teaching challenges, and the success of STEM teaching depends on teachers' understanding and application of STEM (Chai et al., 2020). Therefore, the main purpose of this study is to explore the effect of STEM-PBL advanced mathematics courses in cultivating the PSA of Chinese higher vocational engineering students by conducting teaching experiments to address this research gap.

1.1 STEM-PBL education

STEM education has been promoted as a nationwide education reform program in Europe, the U.S., and other countries. STEM education is designed to strengthen the workforce associated with STEM fields and to develop STEM literacy skills to meet the critical challenges of the 21st century (Ah-Namand and Osman, 2018; Stehle and Peters-Burton, 2019). Literacy developed through STEM education can develop individuals' decision-making abilities, increasing them to understand and solve problems of various real-world (Zollman, 2012). In the United States, a report by the National Science and Technology Council's Commission on STEM Education states that in order to maintain the U.S. advantage in innovation, it is necessary to ensure that the STEM workforce possesses exceptional skills and training (Caratozzolo et al., 2021). In 2016, the Royal Society released a guidebook entitled "Make Education Your Career" to improve comprehensive education in STEM education systems in K-12 schools to ensure that future generations have adequate skills to work in these fields, fostering employment growth and bolstering interest in STEM disciplines (Bunmi et al., 2024).

In addition, it is believed that STEM learning activities will develop abilities, example as creativity, critical thinking and problem solving. Also related to STEM are issues related to humanities such as society, politics and economics (Bear and Skorton, 2018; Gleason, 2020). STEM education also requires the development of ability such as problem solving and the cultivation of literacy in each STEM discipline (Ah-Namand and Osman, 2018; Sasmita et al., 2021). PBL has emerged as a key approach to transforming STEM education by shifting the focus of education from traditional passive knowledge acquisition to active hands-on practice and application (Da-Silva, 2020). Some researchers have concluded through experimental methods that PBL combined with case-based teaching model can help students achieve good academic results and significantly improve their academic performance and learning ability, and said that this teaching model is worth promoting (Yang et al., 2023). Researchers looked into how problem-based STEM projects affected the arithmetic proficiency, attitudes, anxiety, self-efficacy, interests, and viewpoints of seventh-grade pupils (Macun, 2022). The study found that problem-based learning improves students' cooperative, critical, and creative thinking, communication abilities, and collaboration abilities (Sasmita et al., 2021; Susetyarini et al., 2022; Vidákovich, 2021).

However, (Maass et al., 2019) pointed out that because research on STEM education is still in its early stages, there is not enough scientific data to guide the creation of theory, regulations, and application in this field. When we look at the research on STEM, we find that much of this research focuses on the significance of STEM education (Tytler, 2020). Research on STEM education has mostly focused on science teachers, including those who are aspiring, and students in elementary and secondary schools. Very little, if any, has been done on mathematics courses in higher education (Acar et al., 2018; Margot and Kettler, 2019).

Therefore, it is particularly important to integrate vocational mathematics courses into STEM education. By integrating engineering expertise into mathematics courses, students can not only deepen their understanding of science, mathematics and technology knowledge, but also develop the ability to solve practical problems. Students need to apply theoretical knowledge to practice, and finally complete the task through continuous trial and error and adjustment. This process can not only train students' hands-on ability and innovative thinking, but also enhance their interest and enthusiasm in mathematics.

1.2 Research question

Around the world, governments promote STEM education to tackle social and social and economic issues, to population that is literate in science, mathematics and technology. STEM integration is the goal of official policies and reports from government and corporate organizations in many nations. Young people are supported in pursuing STEM-related careers and are encouraged to participate in STEM educations (Chapman and Vivian, 2017; Ritz and Fan, 2015). However, (Maass et al., 2019) pointed out that because research on STEM education is still in its early stages, there is not enough scientific data to guide the creation of theory, regulations, and application in this field. When we look at the research on STEM, we find that much of this research focuses on the significance of STEM education (Tytler, 2020). Research on STEM education has mostly focused on science teachers, including those who are aspiring, and students in elementary and secondary schools. Very little, if any, has been done on mathematics courses in higher education (Acar et al., 2018; Margot and Kettler, 2019).

Therefore, it is particularly important to integrate vocational mathematics courses into STEM education. By integrating engineering expertise into mathematics courses, students can not only deepen their understanding of science, mathematics and technology knowledge, but also develop the ability to solve practical problems. Students need to apply theoretical knowledge to practice, and finally complete the task through continuous trial and error and adjustment. This process can not only train students' hands-on ability and innovative thinking, but also enhance their interest and enthusiasm in mathematics. The research objective is to explore whether STEM-PBL in advanced mathematics teaching can improve students' PSA. Therefore, two important issues were raised that deserve closer examination and are listed below:

1. What is the level of mathematics of EG and CG before the STEM-PBL advanced mathematics intervention?
2. What is the effect of STEM-PBL advanced mathematics on engineering students' problem-solving ability in higher vocational college?

1.3 Conceptual framework

To cope with the challenges faced by higher vocational education in teaching reform, we need to re-examine traditional teaching methods, especially in the process of integrating mathematics and engineering expertise. Integrating STEM courses has become a key path to achieving teaching and learning goals in the 21st century (Roehrig et al., 2021). This study also cuts in from the perspective of constructivist inquiry learning, draws on the deep foundation of STEM education in constructivist theory, and emphasizes that students construct meaning in real problem situations (Woods-McConney et al., 2020). In this framework, we pay special attention to the intrinsic connection between students' PSA and problem-based STEM education (Figure 1).

2 Methods

This study adopted a quasi-experimental method to conduct a 12-week advanced mathematics course teaching for engineering students (Class 1 and Class 2, Grade 2024 of the New Energy Vehicle major) in a certain vocational college. The impact of the teaching results on the PSA of engineering students was evaluated. In this experiment, experimental group (EG) received advanced mathematics teaching using the STEM-PBL method, while control group (CG) received traditional teaching (Stratton, 2019). Before the experiment, the students' mathematical foundation and PSA were assessed through a pre-test (college entrance examination mathematics scores) to ensure that there was no significant difference in the mathematical level of the two groups before the experiment. During the experiment, the researchers tracked the students' learning progress through process tests, evaluated the knowledge mastery and the impact of teaching on students' learning methods and thinking abilities. The post-test used a final exam to evaluate the effectiveness of STEM-PBL teaching. The exam content was consistent with the teaching content, and the difficulty was equivalent to the pre-test, focusing on mathematical PSA (Fıtrıanı et al., 2020; Fülöp, 2021; Klang et al., 2021; Simanjuntak et al., 2021). The EG and the CG used the same test paper and a unified scoring standard to ensure the fairness of the experiment. The schedule for the experiment is as follows (Table 1).

Since the STEM-PBL advanced mathematics course was intended to serve students' majors, it incorporated major course knowledge. The course content was finalized in collaboration with relevant subject teachers after selecting the majors. Firstly, the teaching content was aligned with the teaching syllabus of the course for each cycle: functions, limits, derivatives, integrals, etc. Secondly, the choice of teaching content was combined with major knowledge so that students could understand the application of advanced mathematics in major courses. Thirdly, the content was of moderate difficulty and aligned with the actual level of the students. Fourthly, the content was determined with the aim of teaching the theory and skills in each cycle (Figure 2).

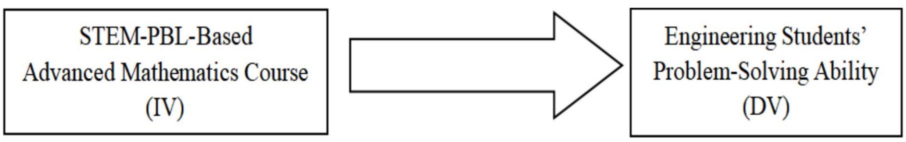

FIGURE 1
Conceptual framework.

TABLE 1 The experiment module.

Step	Week	Theme
Pre-experimental preparation	1–2 (11/11–22/11, 2024)	Pre-test
Formal experiment	3–4 (25/11–6/12, 2024)	The concept and calculation of limit
	5 (9/12–13/12, 2024)	The concept of derivative
	6 (16/12–20/12, 2024)	The application of derivative
	7 (23/12, 2024–27/12, 2024)	The concept and calculation of indefinite integral
	8 (30/12, 2024–3/1, 2025)	The concept of definite integral
	9–10 (6/1–17/1, 2025)	Applications of definite integrals
Late finishing touches	11–12 (20/1–31/1, 2025)	Post-test

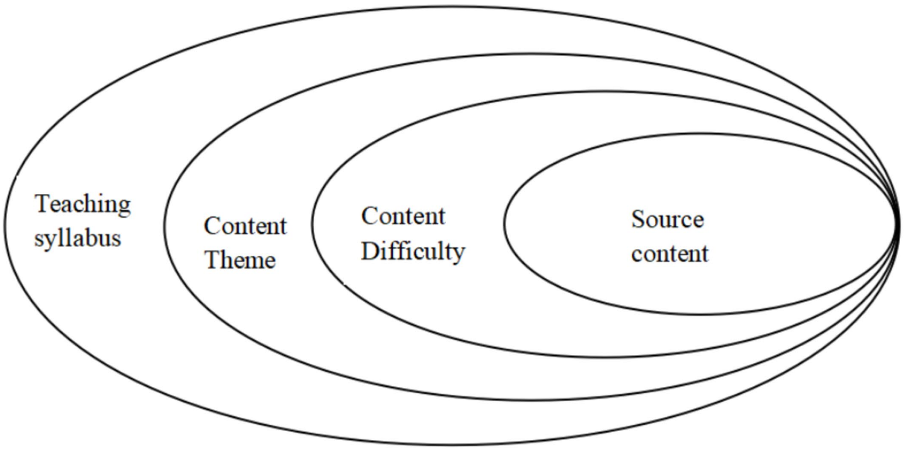

FIGURE 2
Relationship of each criterion for teaching content selection.

FIGURE 3
Screenshot of classroom teaching introduction to the concept of derivative.

The following is a teaching example. Since adjustments may be needed after the first time course based on feedback from students and teacher, the second experimental course (the concept of derivative) will be used as an example. Next, the STEM-PBL-based advanced mathematics classroom teaching process will be demonstrated, in which the teaching content should be integrated with the students' majors (interdisciplinary learning) (Figure 3).

Integrate digital technology into teaching, such as GeoGebra, to vividly demonstrate the geometric meaning of derivatives (Figure 4).

The figure above takes the driving of a new energy vehicle as an example, and gives the time and speed data from 0 to 4 s per second. Students independently explore two questions (average speed and acceleration) to introduce the concept of derivative. Ask questions posted to explore to get a common mathematical expression. Then, post relevant practical problems and discuss them in small groups. Generally speaking, the class is about 41 students, and the students are divided into 5 groups of 7–8 students each, and the grouping is random in principle. Because of the flexibility of college classroom seating, random grouping provides each student with the chance to interact with group members who have diverse perspectives and hear a different opinions during each activity.

During the class, students not only discuss and explore in groups, but also present in groups. There are also math experiment courses, using MATLAB software to solve math problems (Figures 5, 6).

3 Reliability and validity

In quantitative research and measurement, reliability and validity are two key indicators for evaluating the quality of measurement tools (Sürücü and Maslakci, 2020). Reliability emphasizes the consistency and stability of measurement results, that is, whether similar results can be obtained when repeated measurements are made under the same conditions, while validity focuses on whether the measurement tool can accurately and truly measure the target concept (Golafshani, 2003).

FIGURE 4
Screenshot of GeoGebra animation demonstration.

FIGURE 5
Group presentation.

FIGURE 6
Hand-on learning.

TABLE 2 The Pearson correlation coefficient of pre-post test.

		Post-test
Pre-test	Pearson correlation	0.791
	Sig.	0
	Sum of squares and cross product	5642.419
	Covariance	134.343
	N	83

The Pearson correlation coefficient is 0.791, which is higher than the threshold of 0.7 (Hinkle et al., 2003), indicating that there is a strong positive correlation between the pre-test and post-test scores. This means that students with higher pre-test scores tend to get higher scores in the post-test, indicating that the measurement has a certain stability. Since Sig. (p value) = 0, it means that the correlation is statistically very significant (generally $p < 0.05$ is considered significant). This shows that the correlation between the pre-test and post-test is not randomly generated, but is statistically significant. The pre- and post-test data have high reliability and can better reflect the changes in students' mathematics learning level (Table 2).

3.1 The Cronbach's alpha

Cronbach's alpha is considered to be an effective method for evaluating the appropriateness, wording and classification of questionnaire items to ensure internal consistency. In this study, the assessment scale and questionnaire used were used to check the value of Cronbach's Alpha and check the overall consistency of all included items. The results generated are shown in Table 3.

It can be clearly seen from the Table 3 that the Cronbach's alpha coefficients of the test is higher than 0.8, which have passed the internal consistency test and have high reliability.

3.2 Expert review method

Since there is only one set of data in the post-test data and the content of the assigned scores is subjective, we chose to use the expert review method here, and six experts were selected to score the data (1 irrelevant, 2 low correlation, 3 correlation, 4 highly correlation, and 5 highly correlation). The evaluation data are as follows.

According to the Table 4, all six experts believed that the content setting of the assignment was relevant to the research purpose. According to the calculation, the CVR was 1, which was greater than 0.83, so the assignment content had high validity.

TABLE 3 Cronbach's alpha values of questionnaires and tests.

Constructs	Cronbach's alpha	*N*
Pre-post test	0.873	2

TABLE 4 Expert review score.

Number	Score
Expert 1	4
Expert 2	5
Expert 3	5
Expert 4	5
Expert 5	4
Expert 6	5

4 Finding

4.1 Independent samples T-test of pre-test scores of EG and CG

To more intuitively display the distribution of mathematics scores of EG class and CG class at the time of enrollment, we conducted descriptive statistics on the pre-test data of the two classes. The results show that the score distributions of both EG and CG classes present typical bell-shaped curves and both conform to the normal distribution law. According to the Table 5, the average score of both classes is around 65 points, indicating that at the time of enrollment, the mathematics scores of the two classes are comparable and there is no significant difference.

In order to deeply analyze the differences between the EG and the CG in the pre-test stage, this study imported the pre-test scores into SPSS software and performed an independent sample T test. As shown in Table 6, the significance level of the variance homogeneity test is 0.2, which is higher than the critical value of 0.05, indicating that the variances of the two groups of data are homogeneous. At the same time, the significance probability (Sig) of the two-tailed test is 0.96, which is also higher than the threshold of 0.05, so there is no significant difference. Based on this, it can be concluded that before the implementation of the intervention measures, there was no significant difference in the pre-test scores of the students in the experimental group and the control group, and they are at a medium level.

4.2 Independent samples T-test of post-test scores of EG and CG

When conducting an in-depth analysis of the post-test scores of the EG and the CG, we referred to the results of descriptive statistics, which are recorded in detail in Table 7. It can be clearly seen from the table that the average score of the experimental group reached 75.76

TABLE 5 Group statistics of pre-test scores of EG and CG.

	Class	*N*	Mean	Std. deviation	Std. error mean
Pre-test	EG	42	65.05	12.398	1.913
	CE	41	65.22	15.758	2.461

TABLE 6 Independent samples T-test of pre-test scores of EG and CG.

	Levene's test for equality of variances			T-test for equality of means					95% Confidence interval of the difference	
		F	Sig.	*t*	df	Sig. (2-tailed)	Mean difference	Std. error difference	Lower	Upper
Pre-test	Equal variances assumed	1.64	0.20	−0.06	81.00	0.96	−0.17	3.11	−6.36	6.01
	Equal variances not assumed			−0.06	75.91	0.96	−0.17	3.12	−6.38	6.04

TABLE 7 Descriptive statistics of post-test of EG and CG.

	N	Mean	Std. deviation	Skewness	Kurtosis
Post-test_EG	42	75.76	12.064	−0.638	−0.161
Post-test_CG	41	68.54	14.28	−0.559	−0.255

points, which is significantly higher than the average score of the control group, which is 68.54 points. In addition, by observing the absolute values of kurtosis and skewness, we found that the values of these two statistics are less than 2, which further confirms that our data set conforms to the law of normal distribution.

This study aims to analyze the difference in post-test scores between EG and CG students after the implementation of the intervention measures. The researchers imported the post-test data into SPSS software and conducted an independent sample T test. The results show that, as shown in Table 8, the significance level of the variance homogeneity test is 0.23, which exceeds the critical value of 0.05, indicating that the variances of the two groups of data are homogeneous. Furthermore, the significance probability (Sig) of the two-tailed test is 0.015, which is less than the limit of 0.05, indicating that there is a significant difference between the two groups. Therefore, this study concludes that after the implementation of the intervention measures, the students in the EG and the CG showed significant differences in test scores.

Further calculations show that Cohen's *d* is approximately equal to 0.66, ranging from moderate to large effects, indicating that the post test score improvement of EG has practical significance. The variance of approximately 5.2% in η^2 is explained by grouping (EG/CG) and belongs to small to moderate effects. Therefore, STEM-PBL teaching has a moderate effect on students' PSA.

4.3 Paired samples T-test of pre-test scores of EG and CG

The paired sample T test method was used to deeply analyze the difference in PSA between EG and CG in the pre-test and post-test. By inputting the pre-test and post-test data of EG and CG into the statistical software SPSS, we can observe the results shown in the paired sample statistical table in Table 9. It can be clearly seen that the pre-test score mean of EG is 65.05, and the mean of post-test score is 75.76. The pre-test score mean of CG is 65.05, and the mean of post-test score is 68.54. Whether it is EG or CG, the test scores have improved after a period of study or intervention. However, through careful comparison, it can be found that the improvement of the EG's scores is significantly greater than that of the CG. In order to further compare whether the two scores have reached the level of statistical difference, a paired sample T test is required (Table 10).

The correlation between the pre-test scores and post-test scores of EG and CG is 0.632 and 0.878, and the probability *p* value is 0.000. At the significance level, it is less than 0.05, so the null hypothesis is rejected, indicating that there is a significant correlation between them, which is suitable for paired sample T test.

According to the data shown in Table 11, it can be observed that the T values obtained by the EG and the CG after the paired t-test are −6.619 and −2.815, respectively. Further analysis of the probability p value shows that the p value of EG is 0, while the *p*-value of CG is 0.008. Both values are significantly less than 0.05, which the CG group showed significant differences but was weaker than the EG. Therefore, we can conclude that at a significance level of 5%, there is a significant difference between the pre-test scores and the post-test scores of the EG and CG classes. Specifically, the improvement in the scores of students in the EG class is significantly better than that of the CG class. Although the teaching methods of both groups have achieved certain results, the advanced mathematics teaching method based on the STEM concept has shown a more superior teaching effect.

TABLE 8 Independent samples test of post-test of EG and CG.

	Levene's test for equality of variances			T-test for equality of means					95% Confidence interval of the difference	
		F	Sig.	*t*	df	Sig. (2-tailed)	Mean difference	Std. error difference	Lower	Upper
Post-test	Equal variances assumed	1.225	0.230	2.138	81	0.015	6.079	2.844	0.421	11.737
	Equal variances not assumed			2.134	79.024	0.015	6.079	2.848	0.409	11.749

TABLE 9 Paired samples statistics of pre-post test of EG and CG.

		Mean	*N*	Std. deviation	Std. error mean
EG	Pre-test	65.05	42	12.398	1.913
	Post-test	75.76	42	12.064	1.862
CG	Pre-test	65.22	41	15.758	2.461
	Post-test	68.54	41	14.28	2.23

TABLE 10 Paired samples correlations of pre-post test EG and CG.

		N	Correlation	Sig.
EG	Pre-test and post-test	42	0.632	0
CG	Pre-test and post-test	41	0.878	0

TABLE 11 Paired samples test of EG and CG.

		Paired differences			90% Confidence interval of the difference		*t*	df	Sig. (2-tailed)
		Mean	Std. deviation	Std. error mean	Lower	Upper			
EG	Pre-post-test	−10.71	10.49	1.62	−13.44	−7.99	−6.619	41	0
CG	Pre-post-test	−3.32	7.55	1.18	−5.70	−0.936	−2.815	40	0.008

The effect size Cohen's d is about 1.02, which is greater than 0.8, indicating that the experimental intervention has a substantial improvement on the EG group. For CG, Cohen's d is about 0.44, with small to moderate effects, and natural learning or unrelated factors may lead to slight progress.

5 Discussion

5.1 Problem-solving ability of EG and CG students before intervention

Before implementing the STEM-PBL advanced mathematics teaching method, this study conducted a comprehensive assessment of students' problem-solving ability. By analyzing the feedback from students' entrance mathematics test scores, the results showed that there was a small difference between the EG and the CG. Further verification using an independent sample t-test found that there was no significant difference in the mean scores of the two groups of students before the intervention. This shows that before the teaching intervention, the overall PSA of students in the EG and CG groups were at a moderate level, and there was no statistically significant difference.

The results of this study are basically consistent with the evaluation of the mathematical ability in higher vocational colleges by other domestic scholars. According to the 2024 China "Higher Vocational Education Quality Annual Report," a systematic analysis of the mathematical literacy of engineering students was conducted, including multiple aspects of mathematical ability. The research results show that since freshmen in vocational colleges are generally science students, their mathematical ability is generally better than those of students in other majors. The average score of the mathematics entrance test is 68.5 (Xiwu, 2014), which is at a medium level. Taking Xinjiang Industrial Vocational and Technical College as an example, the average score of advanced mathematics in the Department of Metallurgical Engineering for the major of Intelligent Metallurgical Technology for Steel was the lowest, at 53.9 points, the average score of advanced mathematics in the Department of Mechanical and Electrical Engineering for the major of Mechanical and Electrical Equipment Technology was the highest, at 75.2 points (Dong, 2023). Therefore, the average score of mathematics for admission in this study was 65, which is the normal level of mathematics for engineering students in higher vocational colleges.

5.2 Effect of the STEM-PBL advanced mathematics on students' PSA

In this study, the STEM advanced mathematics teaching method was adopted, and after the teaching was implemented, the PSA of the participating students was thoroughly evaluated. Through in-depth analysis of the feedback information in the final mathematics test scores, the results showed that there was a significant difference in PSA between EG receiving the STEM-PBL teaching method and the CG receiving traditional teaching. To further verify this finding, we used the independent sample t-test method for statistical analysis, and the results revealed that there was a significant statistical difference in the average scores of the two groups of students after the teaching intervention. This result strongly proves that after the STEM-PBL advanced mathematics teaching intervention, the students in the EG were significantly better than the CG in PBL, and this difference was statistically significant.

Previous studies have shown that interdisciplinary STEM teaching can effectively improve students' PSA (Li and Gu, 2023), which has been elaborated in detail. Furthermore, STEM is integrated with multiple scientific fields and its presence has become one of the solutions in the education system as students use the knowledge they have acquired to understand problems and design solutions according to STEM education (Salim and Prasetyo, 2018). This research result is consistent with this study. In addition, according to the systematic analysis of 21 relevant documents by Indonesian scholars, about 86% of the articles are based on data results of empirical research, and another 14% of the articles are review comments or theoretical research (Astuti et al., 2021). Studies have shown that physics teaching materials that combine STEM teaching methods with local wisdom can better stimulate students' interest in learning and enhance their learning motivation and autonomy (Agustina et al., 2022; Alfika and Mayasari, 2018). At the same time, STEM-based teaching materials can not only improve students' learning effects in the classroom, but also play a positive role in promoting knowledge transfer and practical ability in off-campus learning environments (Nurazizah and Nurjaman, 2018). More importantly, STEM-PBL-based mathematics teaching helps students transform from knowledge receivers of a single discipline to problem solvers with multiple angles and levels. This transformation is of great significance for cultivating high-quality technical talents for the future.

6 Contributions of the study

This study adopted a quasi-experimental design method to deeply explore the effect of STEM-based advanced mathematics teaching methods on the engineering students' problem-solving ability in higher vocational college. The study not only proposed new insights at the theoretical level, but also achieved remarkable results in practical applications. The main contributions are as follows.

6.1 Records the empirical study of STEM-PBL advanced mathematics teaching in engineering education

Due to the uneven mathematical foundation of engineering students, tight class schedule, lack of practical application links and many other limitations, some researchers and teachers have questioned the feasibility and effectiveness of STEM methods in advanced mathematics classrooms. In recent years, although the concept of STEM education has been gradually promoted, there are few empirical studies in higher mathematics courses, especially in higher vocational and engineering schools. Therefore, this study is an exploratory empirical study on the application of STEM methods in higher mathematics classrooms.

6.2 Propose practical suggestions to optimize the teaching of advanced mathematics

During the course of this study, we encountered a series of challenges and problems. In response to these problems, we put forward the following practical suggestions to improve the teaching methods, textbook content and evaluation system of advanced mathematics in the field of STEM, in order to achieve more efficient teaching results.

Regarding the improvement of teaching methods, it is recommended that teachers adopt a hybrid teaching model, which combines traditional lectures, case analysis, computer simulation and group projects. Such a diversified teaching method can better adapt to the learning needs of students at different levels, thereby improving the pertinence and effectiveness of teaching.

In terms of optimizing textbook design, it is advocated to develop more practical mathematics textbooks. These textbooks should contain interdisciplinary application cases and provide operation guides for modern computing tools such as MATLAB or Python. In this way, students can better master modern computing methods and apply mathematical knowledge to the solution of practical problems.

7 Conclusion

This study adopted a STEM problem-based learning (PBL) advanced mathematics curriculum approach to examine its impact on the problem-solving ability (PSA) of engineering students in a higher vocational college in China. Using a quasi-experimental design, digital tools such as GeoGebra and MATLAB, the study involved 83 students—41 in the experimental group (EG) and 42 in the control group (CG). Data collected through pre-test, post-test, and surveys were analyzed using SPSS. The results showed that mathematics teaching based on STEM-PBL significantly improved students' PSA. Future studies should consider longitudinal designs to explore the sustained effects of STEM-PBL instruction over time. Expanding the sample across multiple institutions and regions could enhance external validity. In addition, incorporating qualitative data—such as classroom observations and student interviews—would provide richer insights into how students engage with STEM-PBL learning.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by SEGi Research Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

JW: Methodology, Writing – original draft, Writing – review & editing, Data curation. PS: Writing – review & editing, Supervision.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

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