The Effects of STEM-PBL Mathematics Module on Secondary Vocational Students' Mathematical Problem-Solving Skills

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Abstract
Purpose：This study aimed to determine the effects of STEM-based education modules and project-based learning on students' mathematical problem-solving ability through the implementation of STEM-PBL teaching modules. In addition, to find out how students perceive the Mathematics STEM-PBL module.
Design/methodology/approach：This study used a quasi-experimental design. Two classes were selected in a secondary vocational school in Sichuan Province, China with a control class, and an experimental class with 35 students in each class. While the control class adopted conventional strategy, the experimental class made use of the STEM-PBL module. Students' attitudes towards STEM-PBL were evaluated using semi-structured interviews, and their aptitude for solving mathematical problems was evaluated by a maths test.
Findings：It was discovered that the STEM-PBL mathematics module enhances students' aptitude for solving mathematical puzzles, and the majority of secondary students had favourable views towards the STEM-PBL mathematics module's instruction. The STEM-PBL module appears to be a promising teaching tool for enhancing mathematical problem-solving abilities.
Research limitations/implication：The STEM-PBL module was effective in improving maths problem solving skills in the short term, but is limited by the experimental design, small sample and short-term implementation, and its long term efficacy and generalisability is yet to be thoroughly investigated.
Practical implications：This study provides educators with ideas for integrating STEM-PBL into the teaching of mathematics in secondary vocational schools.
Originality/value：This study confirms that the STEM-PBL module is effective in enhancing students' mathematical problem-solving skills, particularly in the areas of intuitive imagination, abstraction and modelling, and reveals different student perceptions of this pedagogical approach.

Keywords: STEM, Problem Based Learning, Vocational, Mathematics, Mathematics Education

Introduction

With the acceleration of China's economic restructuring and industrial transformation and upgrading, the structural contradictions in the labour market have been concentrated in a short period of time, resulting in a "skilled labour shortage" and "low-skill trap" (Qian Cheng, 2020). In this context, vocational education has been given a new historical mission and social responsibility (Liu Yue, 2017). And the goal of mathematics curriculum standard of secondary vocational school is to cultivate students' ability to use mathematical knowledge to discover problems and apply mathematical techniques and tools to solve problems (Ministry of Education of the People's Republic of China, 2020, p. 1). This kind of mathematical problem-solving ability is a necessary skill for high-quality technical skills.

However, the mathematical problem-solving skill of secondary vocational students is weak. According to Wang Yu (2014), students' poor mathematical problem-solving skill is mainly reflected in the poor sense of application, participation, cooperation and communication; and teachers are encouraged to combine intuitive thinking with logical thinking such as analysis, induction, abstraction and generalization in teaching. The reason for students' poor mathematical problem-solving skill is that most secondary vocational schools emphasize students' test scores, and it is difficult for students to apply the learned mathematical concepts to real-world problems, and it is also difficult for teachers to teach problem solving methods to students (Chiang & Lee, 2016).

Meanwhile, Zhang, Wen, and Shi (2022) argued that: "Most of the existing studies on strategies to improve mathematical problem-solving ability focus on general education, and there are fewer studies on vocational education, and subsequent studies can be in-depth in this area". Therefore, mathematical problem-solving ability of secondary vocational school students becomes the research gap of this study.

Mathematical problem-solving skill refers to the skill to use comprehensive mathematical knowledge and experience to solve problems effectively and smoothly when encountering problems that cannot be solved directly (Li Dongyan, 2012). Obviously, research on how to improve the mathematical problem-solving skill of secondary vocational students is crucial to solving the current imbalance of talent structure in China.

The integration of STEM education with the PBL (project-based learning) model shows great potential in improving students' learning interest, creativity, and problem-solving ability (Zhou, Ma & Zhou, 2020). STEM curricula emphasize the completion of projects or problem solving through a combination of cooperative, exploratory, and self-directed learning to develop students' creativity and problem-solving ability (Zhou, Ma & Zhou, 2020). Project-based learning (PBL) is one of the popular learning methods in STEM fields (Bedard et al., 2012). PBL not only enhances the motivation of secondary vocational school students, but also improves their problem-solving skills (Chiang, & Lee,2016).

The objectives of STEM education and PBL are the same as those of the secondary vocational school mathematics curriculum, which are to develop students' problem-solving skills. Project-based learning (PBL) and STEM teaching concepts are also intrinsically linked to situational learning theory. All three emphasize problem solving in authentic situation to improve students' problem-solving skills. According to Collins (1988), students are more likely to engage in invention, creativity, and problem solving when they learn in novel and diverse situation. Obviously, the theory of situational learning is consistent with the teaching philosophy of STEM and PBL.

Compared with other countries, China's STEM education started late, and research on teaching practice using STEM concepts to guide vocational education is fewer and shallower. Taking three-dimensional geometry as an example, this study aims to adopt teaching modules combining STEM and PBL, and to explore the effects of STEM-PBL teaching modules on the mathematical problem-solving ability of secondary vocational school students, in order to fill the research gap of this study.

In the pages that following, the following questions will be addressed:
(i) Is there any difference in Mathematical problem-solving skills between the experimental group before and after applying STEM-PBL mathematics module?
(ii) Is there a difference in Mathematical problem-solving skill between the experimental class and the control class after applying STEM-PBL mathematics module?
(iii) What are students' perceptions of STEM-PBL mathematics module?

Literature Review

STEM stands for Science, Technology, Engineering, and Mathematics and was first coined by the National Science Foundation (NSF) in 1990 (Sanders, 2009). Dugger (2010) argues that in the U.S., the acronym STEM was used to enhance STEM education in single disciplines. The discipline-integrated nature of STEM education was expanded upon by later educators (Sander, 2008). Thus, STEM education in the U.S. has gone through a process of gradual integration from separate disciplines, with integration being the direction of development and separate disciplines still coexisting.

The three most used teaching strategies in STEM education are inquiry-based learning (Baharin et al.,2018), problem-based learning (Lou et al.,2011) and project-based learning (Helle et al.,2006; Holubova,2008; Blumenfeld et al.,1991). Although these approaches vary, they all emphasize interdisciplinary integration, collaboration, and problem-solving skills. This suggests that these characteristics of STEM must be used as the basis for teaching and learning to successfully implement STEM education.

Although STEM education in China started late, it has made remarkable achievements in recent years. In terms of theoretical research, it mainly focuses on interpreting educational concepts and integrating teaching methods. Yu Shengquan et al. (2015) argued that STEM is a teaching model, and STEM is an educational philosophy that integrates different disciplines. Shen Yaping (2021) showed that combining the localization of STEM education with elementary science education is the way to implement STEM curriculum in schools.

STEM project-based learning integrates interdisciplinary knowledge of science, technology, engineering, and mathematics and encourages students to actively explore real-world experiences and come up with solutions to real-world problems (Lee & Lee, 2014). Through STEM-PBL (Project-Based Learning in Science, Technology, Engineering, and Mathematics), students are motivated to solve difficulties in their projects, which helps them become better problem solvers (Barron et al.,1998). Prior studies have shown that STEM-PBL is beneficial in improving the mathematical problem-solving skills of secondary vocational school students. Çevik(2018) demonstrated that STEM-PBL strategies favourably impacted the academic performance of vocational high school students. Capraro and Morgan (2013) stated that STEM-PBL fosters student concentration while encouraging peer engagement, collaboration, and problem solving. According to this view, STEM-PBL is a very good tool that can be applied to vocational education.

According to Cai and Lester (2010), the process of solving mathematical problems is known as mathematical problem solving. Mathematical problem-solving gives students the opportunity to practice applying their mathematical knowledge and abilities to solve real-world problems. Secondary vocational mathematics curriculum standards (2020) emphasize that the abilities of Intuitive imagination, Mathematical abstraction, Mathematical modelling, Logical reasoning and Mathematical arithmetic are the basic competencies that students should use to apply mathematical knowledge and thinking to analyse and solve problems. Improving these five competencies helps to improve students' mathematical problem-solving ability.

Based on the five major processes of PISA2015 problem solving, this study combines the situational learning theory, STEM characteristics and the process of PBL activities, and divides the STEM-PBL problem solving ability into six phases: 1) Contextual introduction, exploring and understanding; 2) Building new knowledge, presenting and formulating; 3) Autonomy and collaboration, planning and executing; 4) Process monitoring, reflection and guidance;5) Presentation of results. communication and revision;6) Evaluation project, summary and extension.

This study attempts to investigate the effects of STEM-PBL teaching modules on the mathematical problem-solving ability of Chinese secondary vocational school students, as well as the students' perceptions of the STEM-PBL teaching model to fill the research gap.

Theoretical Framework and Hypothesis Development

Situational learning theory provides a comprehensive theoretical foundation for the development and teaching of STEM-PBL math modules. According to Collins (1988), students are more likely to engage in invention and problem solving when they learn in novel and diverse situation and environments. This is consistent with the pedagogical philosophy of STEM and PBL. In this study, STEM and PBL were combined based on the theory of situational learning to explore the effects of the STEM-PBL mathematics module on the mathematical problem-solving ability of secondary vocational school students. During the implementation of the STEM-PBL modules, students can develop the top five mathematical competencies (Secondary Vocational Mathematics Curriculum Standards,2020)through independent thinking, communication, collaboration, and inquiry, and ultimately improve their problem-solving skills(Zhou, Ma & Zhou, 2020;Chiang, &Lee,2016). The framework links theory, practice, and pedagogical innovations to improve teaching and learning. As shown in Figure 1.

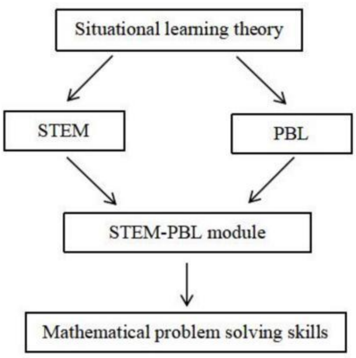

Figure 1: Theoretical Framework

This study proposes the following hypothesis:

Research question 1

H0: There is no significant difference between the experimental group before and after applying STEM-PBL module in Mathematical problem-solving skill.

H1: There is a significant difference between the experimental group before and after applying STEM-PBL module in Mathematical problem-solving skill.

Research question 2

H0: There is no significant difference between the experimental class and the control class after applying STEM-PBL module in Mathematical problem-solving skill.

H1: There is a significant difference between the experimental class and the control class after applying STEM-PBL module in Mathematical problem-solving skill.

Method

This study utilized a quasi-experimental design. Quantitative research was used in the first phase and qualitative research was used in the second phase. The samples of this study came from two natural classes, the experimental class, and the control class, in a secondary vocational school in N city, M province, China. First, to ensure that the initial levels of the experimental and control classes were the same, this study selected two classes with similar grades based on the final grades of the previous semester and neither class had received STEM-PBL education. In addition, to further control the effects of confounding variables on the experimental results, both the experimental and control classes were first-year high school students, and the course content, course duration, and instructors were kept the same in both classes.

In this study, the experimental group utilized the STEM-PBL teaching module and the control group used traditional teaching methods. The research tools for this study included math test questions and structured interview outlines. In the quantitative research phase, quantitative data are collected through pre-tests and post-tests. Before the beginning of the experiment, students in both groups will take a 90-minute pre-test to assess their initial ability to solve math problems. At the end of the experiment, both groups of students will take another post-test to assess changes in their ability to solve math problems. The post-test scores will be categorized into three levels (high, medium, and low) and three students will be randomly selected from each level, for a total of nine students, for structured interviews. In the qualitative phase of the study, a structured interview outline including six interview questions was designed in order to understand the secondary students' perceptions of the STEM-PBL mathematics module. These interview questions were designed to understand students' perceptions of the six aspects of the STEM-PBL program: feelings, satisfaction, interest, expectations, personal growth, and comparison with the traditional program. Each interview lasted approximately 20 minutes. The outline of the interviews was primarily drawn from the interview process, in which the interviewer asked the respondents questions strictly in the order of the questions. Each respondent answered the same questions because collecting standardized interview data facilitates a logical analysis of the interview results.

The purpose is to explore the impact of STEM-PBL math module on Secondary vocational school students' math problem solving skills. The collected quantitative data were first tested positively. If the data obeys normal distribution, paired samples t-test (comparison of pre-test and post-test scores of the experimental group) and independent samples t-test (comparison of pre-test and post-test scores of the experimental and control groups) are conducted on the data of the students' math test scores. If the data did not conform to a normal distribution, nonparametric tests such as the Wilcoxon signed rank test, or the Mann-Whitney U test could be considered. Qualitative analysis Thematic analysis was used to process the data from the structured interviews to understand students' perceptions of the STEM-PBL mathematics teaching module. First, all qualitative data were transcribed verbatim and in detail from the audio recordings. Then, the transcribed text was read carefully and repeatedly to understand the content and underlying meanings. Finally, keywords from the interview transcripts were analyzed and coded to define themes after coding.

Findings

Table 1 shows the results of the paired sample t-test for the pre-test and post-test of the experimental group. The results of the paired sample t-test showed that after applying the STEM-PBL module, the mathematical problem- solving skills of secondary vocational students were significantly improved, t (34) = - 10.619, p < .001.

Table 1 Paired Samples Test for Pre-test and Post-test (experimental group)

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	PreTest - PostTest	-20.68571	11.52433	1.94797	-24.64446	-16.72697	-10.619	34	.000

Table 2 shows the results of pre-test and post-test analysis of 5 mathematical abilities that measure mathematical problem-solving ability. Because the score data of the five ability dimensions did not conform to the normal distribution, a non-parametric test, Wilcoxon signed rank test was used. The results suggest that the STEM-PBL module had a positive impact on all the evaluated mathematical problem-solving skills. The use of the STEM-PBL module led to a significantly greater development in students' mathematical abstraction (z=-4.325b,p<0.01),intuitive imagination(z=-4.634b,p<0.01), mathematical modelling(z=-4.824b,p<0.01), logical reasoning(z=-4.956b,p<0.01), and Mathematical arithmetic abilities(z=-4.416b,p<0.01). The null hypotheses were rejected for each dimension of ability. These results imply that the STEM-PBL module is a potentially useful instructional tool for improving mathematical problem-solving abilities.

Table3 shows the results of the analysis of the math test scores of the experimental and control groups before teaching with the STEM-PBL math module. Since both the experimental class and the control class's pre-test average scores follow the normal distribution, an independent sample t-test was used. independent sample t-test showed a t-value of -0.439, corresponding to a p-value of 0.662 (Sig. (2-tailed)). Since the p-value is greater than 0.05, it indicates that there is no significant difference between the math problem solving skills of the students in the experimental and control classes before the implementation of the STEM-PBL math module implementation. This establishes an appropriate baseline for further research on the effect of the STEM-PBL module on students' math problem solving ability.

Table 2 Test Statistics[a] of pre-test and post-test of the experimental class

	Z	Asymp. Sig.(2-tailed)
Posttest – Pretest Mathematical abstraction ability	−4.325b	.000
Posttest – Pretest Intuitive imagination ability	−4.634b	.000
Posttest – Pretest Mathematical modelling ability	−4.824b	.000
Posttest– Pretest Logical reasoning ability	−4.956b	.000
Posttest – Pr test Mathematical arithmetic ability	−4.416b	.000

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

Table 3 Independent sample Test for pre-test of experimental and control class

		Levene's Test for Equality of Variances		t-test for Equality of Means					
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Pretest total score	Equal variances assumed	.165	.686	-.439	68	.662	- 1.77143	-9.82139	6.27854

Table 4 shows the results of the analysis of the math test scores for the experimental and control groups after teaching with the STEM-PBL math module. An independent sample t test was utilized for analysis since the post-test total scores for the experimental class and the control class follow the normal distribution. independent sample t-test showed a t-value of 2.948, corresponding to a p-value of 0.004 (Sig. (2-tailed)). Since the p-value is less than 0.05, it indicates that after the implementation of the STEM-PBL module, the students in the experimental class have significantly improved their mathematical problem-solving skills by being significantly higher than the control group.

Table 4 Independent sample Test for Post-test of experimental class and control class

		Levene's Test for Equality of Variances		t-test for Equality of Means					
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Posttest Total score	Equal variances assumed	2.382	.127	2.948	68	.004	9.82857	3.17491	16.48223

Table 5 and table 6 show the results of the analysis of the scores of the five ability tests of the experimental and control groups after teaching with the STEM-PBL mathematics module. The results of this study show that the experimental class is significantly better than the control class in terms of Mathematical intuitive imagination ability (t = 3.328, p =. 001), Mathematical abstraction ability (U = 202.500, p= .000), Mathematical modelling ability (U = 386.500, p = .007). However, in terms of Logical reasoning ability (U = 557.500, p = .514), Mathematical arithmetic ability (U = 559.500, p = .524), there is no difference significant difference between the two classes.

Table 5 Independent sample Test for Post-test of experimental and control class (Intuitive imagination ability)

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
							Lower	Upper
Post-test Intuitive imagination	Equal variances assumed	3.903	.052	3.328	.001	2.82857	1.13243	4.52472

To explore students' perceptions of the STEM-PBL math module, nine participants were interviewed based on their performance level on the posttest. The researcher selected three participants from each of the three performance levels, low, medium, and high, to be interviewed.

Table 6 Test Statistics for Post-test of experimental class and control class

	Mann-Whitney U	Z	Asymp. Sig. (2-tailed)
Posttest Mathematical abstraction ability	202.500	-4.861	.000
Posttest Mathematical modelling ability	386.500	-2.705	.007
Posttest Logical reasoning ability	557.500	-.652	.514
Posttest Mathematical arithmetic ability	559.500	-.637	.524

a. Grouping Variable: Group

Table 7 shows the interview themes and the coding associated with them. Specifically, the six themes presented in Table 8 responded to students' overall perceptions of the STEM-PBL math module. The six themes are Feeling of the STEM-PBL, Satisfaction with the results of learning solid geometry, Interest in STEM-PBL courses, Expectations about whether they want to continue teaching in this way in the future, Personal growth experience, Comparison of STEM-PBL classroom with traditional classroom. Specific coding and analysis of the interview texts will follow.

Table 7 Coding table

Theme	Code
Feeling of the STEM-PBL	Freshness and excitement，challenge，pressure，confusion
Satisfaction with learning results	High satisfaction，Medium satisfaction，Low satisfaction
Interest in STEM-PBL	High interest，Medium interest，Low interest
Expectation of continuing the course	Expect，Unexpect
Personal growth experience	Knowledge understanding，collaboration，exchange and communication
Comparison between STEM-PBL and traditional classroom	Cognitive change，value of teamwork，Challenges and difficulties

An excerpt of the interview with one of the participants from high-performance level:

I am very interested in STEM-PBL class. Because it makes me feel differently about the knowledge I learn. It seems that I can understand the connection between knowledge and life.

An excerpt of the interview with one of the participants from moderate-performance level:

My interest in STEM-PBL class is OK. Although sometimes it is a little difficult, but what I learn will make me curious about the three-dimensional objects around me. I'd like to figure out its volume or surface area.

An excerpt of the interview with one of the participants from low-performance level:

I am not interested in STEM-PBL class. I think what I do is a little complicated.

The results of this study show that students have different emotions about the STEM-PBL program. Most students emphasized "freshness", "excitement". A small percentage of students emphasized "challenge", "tension", and "confusion". The top students expressed satisfaction with their academic progress and willingness to continue with the program because they had improved their intellectual understanding, teamwork, and communication skills. For example, "I think I have made great progress in the study of solid geometry. I made a solid geometry lamp." Students with poor grades mainly expressed dissatisfaction and did not want to continue with the program. For example, "In the part of solid geometry, I think my learning achievement score group is not very good, and I still need to make more efforts ". On the other hand, students with moderate scores showed moderate satisfaction and willingness to continue the course because their collaboration and communication skills improved to some extent, but they also indicated that what they learned needs to be strengthened. The results of this study showed that the students' interest and satisfaction in the STEM-PBL program were almost the same. These are expressions of students' attitudes towards the STEM-PBL classroom and reflect that the implementation of the STEM-PBL module had a positive impact on students' mathematics learning.

In a comparison of the STEM-PBL program with a traditional program, most students found the program engaging, interesting, and valued teamwork. However, some students also experienced difficulties and challenges in the STEM-PBL classroom. For example, one student stated "I think STEM-PBL classroom is very different from traditional classroom. There are many lessons in this class, but sometimes it' s a little difficult for me". s a little difficult for me". This could be due to the imbalance caused by the change in teaching methods, where underperforming students have not yet adapted to the new teaching methods.

Discussion

The results of this study show that after applying the STEM-PBL module, the mathematical problem- solving skills of secondary vocational students were significantly improved. This finding is supported by related research. Studies have shown that this STEM education can help students develop mathematical problem-solving skills (Prawvichien, Siripun, and Yuenyong, 2018),and there was a significant improvement in the mathematical problem-solving skills of students after receiving this program (Priatna&Juandi,2021).This result may be related to the characteristics of STEM-PBL, which are interdisciplinary learning and project-based learning.Zollman (2012) stated that interdisciplinary learning is essential for developing students' STEM literacy (the ability to understand and use materials from STEM disciplines to solve real-world problems). On the other hand, Fisher et al. (2021) showed that Project-Based Learning (PBL) is effective in improving students' mathematical problem-solving skills. This is because this type of learning is based on real-world practices and real-life problems (Al-Balushi & Al-Aamri,2014)), resulting in meaningful learning experiences (Wurdinger et al., 2007). Project-based learning also provides students with learning modes of questioning, investigation, data collection, data analysis, and drawing conclusions to provide opportunities to construct knowledge and solve real-world problems (Blumenfeld et al., 2000).

The results of this study show that after the implementation of the instructional intervention, the STEM-PBL instructional module significantly improved students' problem-solving skills more than the traditional instructional approach. This finding is consistent with earlier research. It was found that students who received STEM-PBL instruction improved their problem-solving skills more quickly than students who received traditional instruction (Priatna & Juandi, 2021). This may be because PBL mostly involves project activities in the form of teamwork to develop students' thinking skills. creativity, and encourage students to cooperate with each other, emphasizing students' voluntary participation in intentional learning activities (Bédard et al, 2012). PBL focuses on teamwork to achieve students' goal of solving complex problems in authentic situations (Hârtescu,2014). The STEM curriculum is the starting point of STEM education and emphasizes the completion of projects or problem solving through a combination of collaboration, exploration, and self-directed learning; it aims to increase students' interest in learning and to develop their creativity and problem solving skills(Zhou,Ma & Zhou,2020).These characteristics are lacking in traditional teaching methods; therefore, after the implementation of instructional interventions, the STEM-PBL teaching module improved students' problem-solving skills more significantly than traditional teaching methods.

In addition, this study also demonstrated that the implementation of the STEM-PBL mathematics module had different effects on the 5 mathematical abilities. This may be since the STEM-PBL program is not intended to address this component of students' thinking skills. In terms of developing students' mathematical computational skills, traditional math instruction has placed more emphasis on this. As a result, there was no significant improvement in the mathematical arithmetic ability of the experimental class compared to the control class. This suggests that STEM-PBL instruction had little to no impact on students' mathematical arithmetic ability when compared to traditional teaching methods. These results, in turn, imply that STEM-PBL modules can significantly improve key aspects of mathematical problem-solving ability, especially mathematical abstraction, mathematical modeling, and visual imagination.

The interview results showed that the implementation of the STEM-PBL module had a positive impact on students' mathematics learning. This finding is supported by Lou et al. (2011), who concluded that STEM-PBL can lead to students exhibiting positive attitudes, acquiring integrated conceptual and procedural knowledge, and demonstrating positive behavioral intentions. Also, the results of these interviews showed that high-achieving students had more positive attitudes toward STEM-PBL. This is consistent with previous findings. The higher the students' GPA, the more positive their attitudes toward STEM-PBL (Shojaee, Cui, Shahidi, & Zhang, 2019). However, some students also experienced difficulties and challenges in the STEM-PBL classroom. According to Awla (2014), students perform better if the teacher's teaching method or instruction matches their learning style. Therefore, educators should rethink how students at different performance levels can benefit from participating in STEM-BPL activities and be guided to adapt their instructional strategies to engage diverse learners in the classroom (Han, Capraro & Capraro, 2015).

Conclusion

The results of the study not only demonstrated a significant improvement in the math problem solving skills of the students in the experimental class after the implementation of the STEM-PBL module, but the results of the study also demonstrated a significant improvement in the problem-solving skills of the students who were taught the STEM-PBL module as compared to the students who were taught the traditional instruction. The results of this study provide educators with a new pathway for instruction. Educators can adapt and select appropriate instructional strategies based on the competency needs of their students. In other words, they can use STEM-PBL extensively in teaching and learning to improve the mathematical problem-solving skills mentioned in the Mathematics Curriculum Standards for Secondary Vocational Schools. Since this study proved that the STEM-PBL program is effective in improving students' mathematical problem-solving skills, educational institutions may consider whether to incorporate STEM-PBL, a teaching method, into secondary vocational school mathematics curricula, and whether to train teachers in STEM-PBL teaching skills to further develop STEM teaching and learning.

The results of the study also proved that the class after the implementation of the STEM-PBL module was significantly better than the class with the implementation of the traditional teaching in terms of mathematical intuitive imagination, abstraction and modeling skills. Whereas, in mathematical operations and logical thinking skills, the difference in abilities between the two classes was not significant. In future practice, educators may prioritize STEM-

PBL instructional methods when improving students' mathematical visual imagination, abstraction, and modeling skills. Traditional instructional methods may also be needed as a supplement in mathematical operations and logical thinking skills. Students can make the leap from improving five math skills to improving math problem solving skills in this instructional model. Further research could provide an in-depth analysis of the factors in the STEM-PBL module that led to a lack of improvement in students' mathematical arithmetic and logical thinking skills and explore ways to improve these two competencies and maximize students' mathematical problem-solving skills in a STEM-PBL course.

The results of the qualitative study demonstrated that students had different perceptions of the STEM-PBL classroom. The majority of students showed positive attitudes toward the STEM-PBL classroom. While other underperforming students indicated that this teaching method was difficult and challenging to adapt. In future educational practices, students who have positive attitudes toward STEM-PBL classes can continue to be taught using this method. For students who have difficulty adapting to the STEM-PBL program, teaching strategies may need to be adjusted by giving more time to guide students to adapt to the program by providing more support. At the same time, different students have different knowledge and abilities, and teachers may need to understand all aspects of their students and design their courses to take their differences into account so that they can tailor their instruction to their talents. Further research could analyze the factors that contribute to students' difficulties in adapting to STEM-PBL courses and students' perceptions of STEM-PBL courses as challenging.

From the perspective of the whole quasi-experimental study. The purpose of this study was to examine the effect of the STEM-PBL mathematics module on students' problem-solving skills and students' perceptions of the STEM-PBL math module. The results of this study are instructive for future research on project-based learning (PBL) and STEM education and provide a compelling argument for further research on how STEM-PBL instructional modules can improve students' mathematical problem-solving skills. However, the experimental design and methodology used in this study limit the applicability of the findings. Confounding factors other than the STEM-PBL math module may have had an impact on the results of the experimental study. For example, the experimental results may first be influenced by students' prior knowledge, motivation, attitudes, and learning preferences. The sample size of this study (70 students) was too small, which may limit the validity and generalizability of the findings. The STEM-PBL module was only used in the experiment for two weeks, so there is no information on its long-term effects. The findings of this study do not adequately capture the long-term effects of STEM-PBL on problem-solving skills.

Although this study has shed some light on the effectiveness of the STEM-PBL instructional modules, some suggestions for future research are made here based on the limitations of the study. Future studies could focus on the performance of STEM-PBL modules in various subject areas or increase the sample size to better understand the generalizability of the findings and the effectiveness of STEM-PBL programs. In addition to this, follow-up studies could increase the length of the study to determine if students' mathematical problem-solving skills improve over time and if their positive attitudes toward the STEM-PBL program continue to be maintained.

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