ORIGINAL ARTICLE

Implementation of Project Based Learning (PjBL) in Mathematics Education: A Systematic Analysis of International Practices and Theoretical Foundations

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***Abstract**: Project Based Learning (PjBL) has emerged as a promising approach in mathematics education. This study aims to analyze the implementation of project-based learning (PjBL) internationally in mathematics education and to identify the underlying learning theories, such as the method of writing an article through SLR. A systematic literature review uses the "Publish or Perish" application for Scopus and Crossref searches. The selection criteria include accredited journal articles from Sinta 1, Sinta 2, or those already accredited by Scopus from 2014 to 2024 in English, focusing on mathematics/mathematics education. Out of the ten selected articles, further analysis was conducted. PjBL effectively enhances academic achievement. 21st-century skills include critical thinking, problem-solving, collaboration, communication, creativity, technological literacy, and student motivation in mathematics education across various countries. Implementing the PjBL model in mathematics involves a series of well-defined steps: presenting problems, preparing project plans and schedules, forming effective teams, providing support, integrating with the curriculum, using visual media, presenting and evaluating results, and reflecting on the process. The implementation challenges include inflexible schedules and teachers' need for more professional skills. The theories underlying the effectiveness of PjBL include constructivism, social learning, experiential learning, multiple intelligences, contextual learning, motivation, and problem-solving. PjBL shows significant potential in enhancing international mathematics learning. Implementation*

success depends on thorough preparation, appropriate support, and adjustments to the local context. Further research is needed to optimize the integration of PjBL with traditional methods, address implementation challenges, and analyze its long-term impacts.

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Introduction

IN AN ERA of constantly evolving education, we face the challenge of preparing the younger generation to confront an increasingly complex world. For mathematics learning, often seen as a nightmare for many students, new ways are needed to teach concepts and foster creativity and problem-solving abilities. Project-based Learning (PjBL) is an educational method through which students learn through involvement in real and meaningful projects. This method is proven to enhance a variety of 21st-century skills that are critical for success in today's rapidly changing world. These skills include critical thinking (Zayyinah et al., 2022), problem-solving, collaboration (Aifan, 2021), communication, creativity, and technological literacy (Martínez, 2022). However, implementing PjBL in various international contexts and integrating learning theories into PjBL practice still require further research.

In math class, students memorize formulas and apply them to their chosen real projects. A class where active discussions, team collaboration, and the discovery of creative solutions become daily activities. This is the essence of PjBL, which has begun to transform the face of mathematics education in various parts of the world (Dimitra Kokotsaki et al., 2016). Recent research is beginning to show the great potential of PjBL in mathematics education. A study conducted by (Han et al., 2015) indicates that PJBL enhances academic achievement and helps bridge the gap between high-performing and low-performing students. This opens up the possibility that PjBL can be a means of creating more inclusive and equitable mathematics education.

In the context of modern education, 'formal education' starting from the school phase from primary education to higher education, can use the PjBL learning model (Fernandes et al., 2014) (Guo et al., 2020), which refers to a structured education system that combines a standard curriculum with a PjBL approach. This formal education usually takes place at a recognized educational institution, such as a school or university, where students follow a predetermined educational program but with particular emphasis on project-centered learning experiences (Chikurteva & Chikurtev, 2020) (Ozório et al., 2021). By combining the structure of formal education with the flexibility and relevance of PjBL, this model seeks to bridge the gap between theoretical learning and practical application in the real world.

Furthermore, PjBL aligns with modern learning theories that emphasize the importance of active knowledge construction by students. As expressed by (Tamim & Grant, 2013), PjBL allows students to construct their understanding, a principle that aligns closely with constructivist theory. This allows students to see mathematics not as a collection of formulas to be memorized but as a helpful tool in everyday life. However, despite its great

potential, implementing PjBL in mathematics education takes time and effort. (Bray & Tangney, 2016) remind us that the success of PjBL heavily relies on thorough preparation and appropriate support for students. In addition, the role of learning theories in the context of PjBL is also an important aspect that needs further exploration. Theories such as constructivism, experiential learning, and multiple intelligences are often associated with PjBL, but their practical implementation in mathematics education still requires further research (Dimitra Kokotsaki et al., 2016).

Recent studies show that PjBL has significant potential in improving students' mathematics achievement. For example, research conducted by (Lazić et al., 2021) in Serbia found that students who learned using the PjBL model achieved better results than those taught with conventional methods. Similar findings were reported by (del Valle-Ramón et al., 2020) in Spain, which indicated a more significant increase in mathematical knowledge among the group using PjBL. Nevertheless, implementing project-based learning (PjBL) also faces various challenges (Viro et al., 2020) identified several obstacles, including inflexible schedules, a lack of professional skills and motivation among teachers, and resource limitations. This indicates the need for a deeper understanding of how PjBL can be effectively integrated into the mathematics curriculum and how teachers can be supported in implementing this approach.

In this context, a systematic literature review (SLR) is essential to analyze the current application of international project-based learning (PjBL) in mathematics education and identify the learning theories directly implemented within the PjBL context. This SLR aims to synthesize the latest findings, identify best practices, and reveal gaps in existing research. Conducting this SLR aims to provide comprehensive insight into the effectiveness of PjBL in mathematics education, successful implementation strategies, and the integration of relevant learning theories. The results of this SLR can serve as a foundation for developing more effective and innovative mathematics teaching practices and provide direction for future research in mathematics education.

Research Methods

SLR aims to identify all relevant research (Petticrew & Roberts, 2008) to answer a specific question and assess the validity of each study by considering established criteria until concluding (Suri, 2020; Okoli & Schabram, 2012). The steps taken in the SLR research are adapted from (Himmi et al., 2023) as follows:

Developing Research Questions

In this study, the research questions were prepared based on the background described previously. Including:

Q1: How is the application of PjBL currently implemented internationally in mathematics education?

Q2: How are learning theories implemented in mathematics education within project-based learning (PjBL)?

Article Selection Criteria

In selecting the articles to be analyzed in depth for this research, inclusion and exclusion criteria have been established to address the research questions effectively (**Figure 1**). The criteria are as follows:

Developing Search Strategies

Searching for articles using the "Publish or Perish" application with the keywords "project-based learning, PBL implementation, learning theories in PjBL" in the Scopus Search menu.

Selection Process and Assessment of Article Quality

After obtaining articles through the search strategy, a review was conducted to assess the articles' suitability and compliance with the predetermined selection criteria. The steps are:

1. Evaluate titles, abstracts, and journal texts that contain the keywords project-based learning, PjBL implementation, and learning theories in PjBL
2. Choose articles published by Scopus or at least SINTA 2. SINTA (Science and Technology Index) is a ranking and indexing system developed by the Indonesian Ministry of Research, Technology, and Higher Education to improve the quality and visibility of domestic scientific publications. This system uses a ranking scale of six levels, from SINTA 1 to SINTA 6. SINTA 1 is the highest rating usually given to journals indexed in international databases such as Scopus or Web of Science. This ranking reflects the quality and impact of journals based on various predetermined criteria.
3. Focus on articles published in recent years to ensure the information and findings reflect recent developments in the field under study.
4. Priority is given to articles in English, given its status as the lingua franca in the global scientific community. This allows access to a broader spectrum of research and facilitates cross-country comparisons.
5. According to the specific research theme, the selected articles are in mathematics and mathematics education.

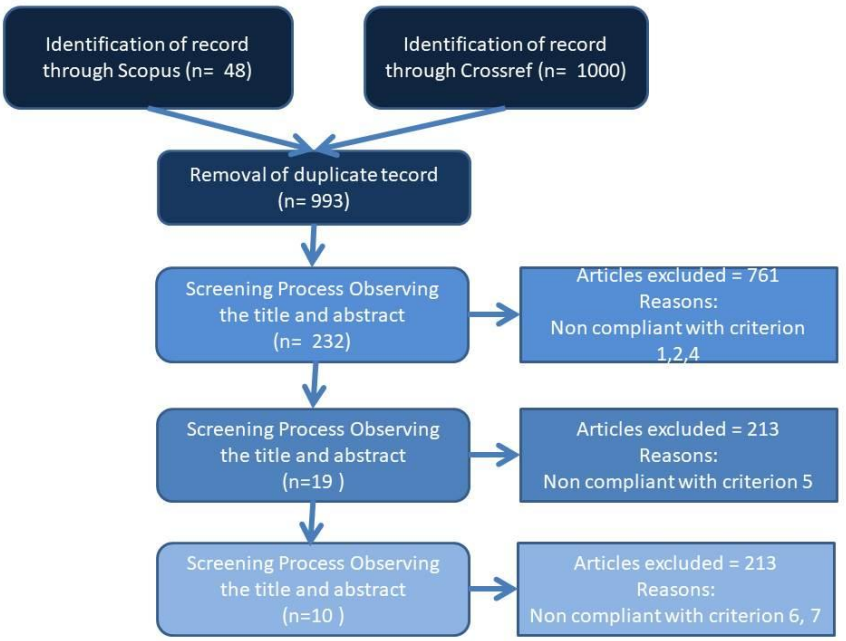

Figure 1. Flowchart of the Article Selection Procedure.

6. The use of quantitative methods in research is one of the criteria that make it possible to generalize the findings.
7. The selected articles have research subjects in the context of formal education. This is important to ensure the relevance of the findings and analysis to structure and officially recognized educational settings, such as schools or colleges, which use standard curricula and established teaching methods.

Applying these criteria helps ensure that the selected articles provide a sound and relevant basis for the research.

Synthesis Results

This synthesis analysis examined all articles obtained from search results using the Publish or Perish application and entered the specified keywords. Next, search results are filtered based on predetermined criteria, resulting in the image below:

Results and Discussion

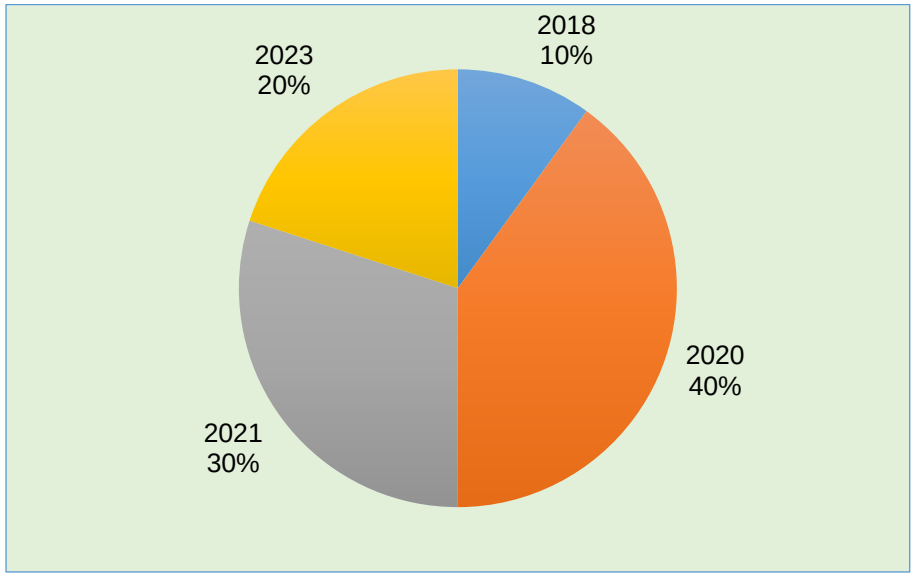

Figure 2. Percentage of Articles.

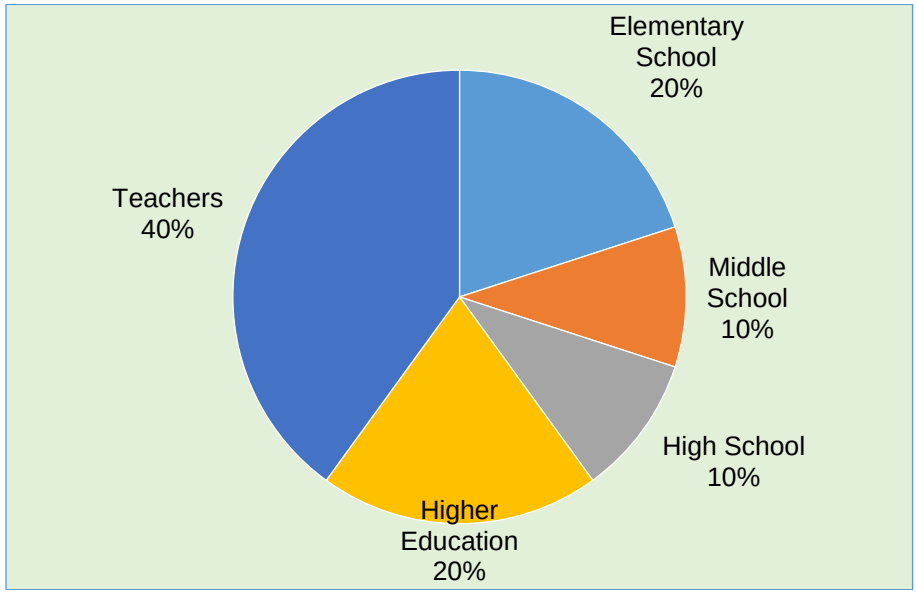

Figure 3. Percentage of Research Subjects.

Table 1: Selection Criteria Table.

No	Criteria	Inclusion	Exclusion
1	Publication Type	Articles used are from journals	theses, brief reports, and non-empirical studies
2	Specific Journal	Accredited journals at least Sinta 2 and international journals indexed by Scopus	non-accredited journals, or journals from Sinta 3-6 as well as international journals not indexed by Scopus
3	Publication Year	Articles published from 2014 to 2024	articles published outside the specified timeframe
4	Language	In English	Not in English
5	Field	Mathematics, Mathematics Education	not Mathematics, Mathematics Education
6	Method	Quantitative	Not Quantitative
7	Research Subject	Formal Education	Non-Formal Education

Ten articles that meet the established criteria were obtained based on the synthesis results of the available articles. As for the distribution of the article, as shown in **figure 2**:

Based on **figure 2**, **figure 3**, and **table 1**, it is obtained that 40% of the total articles are from the year 2020, 50% of the research designs are quasi-experimental, and 40% of the research subjects come from elementary schools.

The Application of PjBL in Mathematics Learning Internationally

Project Based Learning (PjBL) has become an increasingly popular approach in mathematics education across various countries. Research shows that PjBL enhances academic achievement and develops essential 21st-century skills for students. Several European countries have implemented PjBL in mathematics education with promising results. In Finland, (Viro et al., 2020) found that PjBL is an effective method for developing mathematical competencies and 21st-century skills. PjBL facilitates the development of teamwork skills and helps students connect mathematical theory with its practical applications. However, this research also identifies several challenges in implementing PjBL, such as inflexible schedules and teachers' need for more professional skills.

The study in Serbia by (Lazić et al., 2021) shows encouraging results. Elementary school students who learn with the PjBL model achieve better results than those who use conventional teaching methods. Interestingly, PjBL has proven effective in improving the performance of all students, including those who previously had low math scores. In Spain, (del Valle-Ramón et al., 2020) reported that students using PjBL showed a more

significant mathematical knowledge improvement than the control group. In addition, students who use PjBL are much more satisfied with this learning method. Research in Russia by (Rozhkova et al., 2020) at the higher education level also shows positive results. Engineering students who used PjBL showed better learning outcomes than those in the control group. Most students (84%) responded positively to using project-based methods in mathematics learning, with the main benefits perceived including improved teamwork skills, the development of independent learning skills, and an expanded perspective.

In Asia, research in Indonesia by (Septian et al., 2020) shows that PjBL effectively enhances students' mathematical representation skills. Meanwhile, (Hartono, 2018) reported a highly positive response (85.83%) from junior high school students towards project-based learning, with a significant difference between pretest and post-test results. Nevertheless, the implementation of PjBL in mathematics education can be challenging. (Diego-Mantecon et al., 2021) Mathematics teachers in Spain tend to avoid transdisciplinary projects and focus more on interdisciplinary projects emphasizing mathematics. Although there was no significant improvement in math scores, this study shows that the knowledge gained through PjBL tends to last longer.

In addition to the analyzed article (**Table 2**), it was also found that the United States (Remijan, 2016) discovered that PjBL can motivate high school students to learn mathematics, primarily when the projects focus on design and are relevant to real life. (Mdaka et al., 2023) In South Africa, They use teaching strategies that help students develop learning styles that facilitate shared experiences and collective reflection. In Turkey, (Ayaz & Söylemez, 2015) conducted a meta-analysis showing that PjBL significantly positively affects students' academic performance in mathematics compared to traditional teaching methods. In addition, a study by (Han et al., 2015) in Texas showed that PjBL in the context of STEM can affect student performance differently based on their ability levels, with a significant positive impact on low- and medium-performing students. Then, research (Frykholm & Glasson, 2005) describes how PBL can integrate mathematics with science, providing a meaningful context for students to apply mathematical concepts.

Overall, the implementation of PjBL in international mathematics education shows promising results. PjBL enhances academic achievement and develops essential skills such as teamwork, independent learning, and connecting mathematics with the real world. However, the success of PjBL implementation dramatically depends on thorough preparation, appropriate support for students and teachers, and adjustments to the local context and specific needs of the students.

Table 2: Article Analysis.

Code	Author	Research Design	Country	Results
P1	(Viro et al., 2020)	Experiment, Research Subjects Pre-service and In-service Teachers	Finland, Europe	PjBL is considered a development of mathematical/scientific competencies and 21st-century skills. The characteristics of project-based learning include developing teamwork skills and connecting theory and practice. PjBL is deemed suitable for revising and studying new mathematical content. The main obstacles to implementing Project-Based Learning (PjBL) include inflexible schedules, a lack of professional skills and motivation among teachers, and insufficient resources.
P2	(Lazić et al., 2021)	Quasi-Experimental, Research Subjects Third Grade Elementary School Students	Serbia, Europe	Students who learn with the PjBL students who learn with traditional methods. PjBL enhances the performance of all students, regardless of their previous math scores. Significant improvement is even observed among students with low scores. There is a significant interaction between the teaching method (PjBL) and students' math scores regarding their performance.
P3	(del Valle-Ramón et al., 2020)	Quasi-Experimental, Research Subjects Fifth Grade Elementary School Students	Spayol, Europe	The experimental group showed a more significant increase in mathematical knowledge than the control group. Students in the experimental group had much higher satisfaction with the learning method than the control group. Group work in PBL is effective in achieving learning objectives.
P4	(Septian et al., 2020)	Quasi-experimental, research subjects are students from the Mathematics Education Study Program	Indonesia, Asia	The achievement and increase in mathematical representation abilities in the experimental group were superior to those in the control group. The achievement of mathematical representation skill indicators in the experimental group is good, while the control group is adequate. The achievement of indicators based on cognitive styles in the experimental group is classified as good, whereas in the control group, it is classified as adequate. The PjBL model assisted by GeoGebra effectively enhances students' mathematical representation skills.
P5	(Hossein-Mohand et al., 2021)	Cross-sectional, the subjects of the research are secondary school mathematics teachers	Spain, Europe	The Flipped Learning, Project-Based Learning, and Gamification models positively impact several evaluated indicators. Project-based learning shows a negative relationship between two aspects of teaching practice indicators. These aspects include exchanging information and content through online spaces, participating in school projects related to digital technology, and using educational software to teach mathematics. They significantly impact the selection of active learning models and methodologies. ICT training and mathematics teachers' uses of technology are relatively minor in selecting models and methodologies.
P6	(Diego-Mantecon et al., 2021)	Experiment, Research Subjects: Mathematics, Physics, Chemistry, Biology, and Secondary School Technology Teacher	Spain, Europe	Out of 41 projects, 25 integrate mathematics content. Mathematics teachers avoid transdisciplinary projects and focus more on interdisciplinary projects emphasizing mathematics. Non-mathematics teachers need to pay more attention to the mathematical aspects of interdisciplinary projects. Interdisciplinary projects facilitate the development of mathematics more than transdisciplinary projects do. There is no improvement in students' math scores, but the knowledge gained lasts longer.
P7	(Rozhkova et al., 2020)	Experiment, Research Subjects: Engineering Students	Russia, Europe	The group using PjBL showed better learning outcomes than the control group. 84% of students responded positively to using project-based methods in mathematics learning. The main benefits of PjBL, according to the students, are teamwork skills (86%), development of independent learning skills (84%), and broadening of perspectives (83%). The project method helps students see the application of mathematics in real life and increases their interest in learning.
P8	(Hartono, 2018)	Quasi-Experiment, Research Subjects: Seventh Grade	Indonesia, Asia	The positive response of students to project-based learning (PBL) is 85.83%. There is a difference in student learning outcomes before and after

		Students of Junior High Schoo		implementing PjBL. The t-test results indicate a significant difference between the pretest and post-test.
P9	(Remijan, 2016)	Quasi-Experiment, Eleventh Grade Students of High School	Indonesia, Asia	Both learning models (STEM Project-Based Learning and STEM Problem-Based Learning) can enhance students' critical thinking skills. STEM PjBL is more effective in improving critical thinking skills than STEM PBL. There is a significant difference between the two learning models regarding enhancing critical thinking skills (Sig. 2-tailed = 0.01).
P10	(Monika et al., 2023)	Survey, Mathematics, Physics, Chemistry, Biology, and Technology Teachers in Malaysia	Malaysia, Asia	The knowledge and attitudes of teachers gained from professional development are high. Teachers' skills are at a moderate level. Teachers' knowledge, skills, and attitudes vary from moderate to high levels.

Learning Theories Used in Mathematics Education

Project Based Learning (PjBL) in mathematics education is supported by various learning theories emphasizing the importance of active student engagement, real-world contexts, and the development of complex skills. Several theories underpinning the effectiveness of Project-Based Learning (PjBL) based on research findings are as follows:

1. Constructivist theory was developed by figures such as Jean Piaget and Lev Vygotsky. This theory emphasizes that learning occurs when students actively build their knowledge. This is reflected in the findings of (Viro et al., 2020), which show that Project-Based Learning (PjBL) facilitates the connection between theory and practice in mathematics education. Students do not just passively receive information but actively construct their understanding through project experiences.
2. Vygotsky's social learning theory emphasizes the importance of social interaction in learning, supporting project-based learning (PjBL). (Rozhkova et al., 2020) They reported that one of the main benefits of PjBL is enhancing teamwork skills. This aligns with Vygotsky's concept of the Zone of Proximal Development, where students can achieve a higher level of understanding through collaboration with peers and teacher guidance.
3. The Experiential Learning Theory, developed by David Kolb, emphasizes the importance of concrete experience and reflection in learning. The findings (del Valle-Ramón et al., 2020) that show high student satisfaction with Project-Based Learning reflect how learning through hands-on experiences can enhance student motivation and understanding.
4. Howard Gardner's Theory of Multiple Intelligences. Project-based learning (PjBL) allows students to utilize various intelligences to

complete projects. This is reflected in the findings of (Septian et al., 2020), which show that Project-Based Learning (PjBL) effectively enhances students' mathematical representation skills involving various forms of intelligence.

5. Contextual Learning Theory, which emphasizes the importance of connecting learning with real-world situations, is very much in line with project-based learning (PjBL). (Hartono, 2018) reported a highly positive response from students towards PjBL, which may be attributed to the relevance of the projects to the students' real lives.
6. Motivation theories, such as the Self-Determination Theory developed by Ryan and Deci, also support PjBL. (Lazić et al., 2021) found that PjBL effectively improves the performance of all students, including those who previously performed poorly. This may be due to the increase in students' intrinsic motivation when they engage in meaningful projects.
7. Problem-solving theory, as developed by George Polya, is also relevant to PjBL (Diego-Mantecon et al., 2021) show that although there is no significant increase in math scores, the knowledge gained through PjBL tends to be more enduring. This may be due to the in-depth problem-solving approach inherent in PjBL.

Apart from the learning theories that have been put forward in the findings above, several additional theories support the effectiveness of PjBL in mathematics learning, including Situated Learning Theory (Lave & Wenger, 2013) which emphasizes that the most effective learning occurs in social contexts and authentic situations, which is in line with PjBL principles. Cognitive Apprenticeship Theory (Collins et al., 1991) describes how learning can be enhanced through observation, mentoring, and practice in authentic contexts, critical elements in PjBL. Self-Regulated Learning Theory (Zimmerman, 2022) explains the importance of students' ability to regulate their learning, which can be developed through PjBL. Connectivism theory (Siemens et al., 2005) emphasizes the importance of connections and networks in the digital era, which can be facilitated through collaborative projects in PjBL.

Based on the results of a synthesis of various articles, it was found that the main steps in implementing PJBL in mathematics learning include: a) Start by presenting a real-world problem or challenge that is relevant to the mathematical concepts being taught. This engages students and provides context for their learning (Tarakova, 2022; D Kokotsaki et al., 2016); b) Develop detailed project plans that outline the objectives, tasks, and expected outcomes. This includes defining the criteria that the project problem must satisfy (Fernandes et al., 2014; Tarakova, 2022); c) Creating a timeline for project activities, ensuring that students have a clear understanding of deadlines and milestones (Fernandes et al., 2014; Tarakova,

2022); d) organizing students into teams to foster collaboration and peer learning. This step is crucial for developing teamwork and communication skills (D Kokotsaki et al., 2016; Fernandes et al., 2014); e) Offer continuous support and guidance throughout the project. This includes monitoring project implementation and providing necessary resources and tools (D Kokotsaki et al., 2016; Azizah et al., 2023); f) Ensure that the projects are aligned with the curriculum and learning objectives. This helps in making the learning experience more relevant and comprehensive (Azizah et al., 2023; D Kokotsaki et al., 2016); g) Incorporate visual media to enhance understanding and engagement. Visual aids can help students grasp complex mathematical concepts more easily; h) Have students present their project results through written reports, oral presentations, or other formats. This step helps in reinforcing their learning and improving communication skills (Tarakova, 2022; Fernandes et al., 2014); i) Conduct a comprehensive performance-based evaluation to assess the effectiveness of the project and the learning outcomes. This includes both self-assessment and teacher assessment (D Kokotsaki et al., 2016; Fernandes et al., 2014) and j). After the project is completed, reflect on the process and outcomes. Use this reflection to make necessary adjustments and improvements for future projects (Guo et al., 2020).

Applying the project-based learning model to mathematics education significantly enhances students' understanding (D Kokotsaki et al., 2016), engagement (Tarakova, 2022), and achievement (Sumartini et al., 2019). It promotes the development of essential skills such as problem-solving, critical thinking, and teamwork, making mathematics learning more effective and relevant to real-world applications (Guo et al., 2020). Integrating visual media further enriches this learning experience (Lizunkov et al., 2020), providing students with a clearer and more engaging understanding of mathematical concepts.

Overall, PjBL in mathematics learning is supported by various learning theories emphasizing the importance of active student involvement, authentic context, collaboration, and the development of complex skills. Integrating these theories in Project-Based Learning (PjBL) helps explain its effectiveness in enhancing students' mathematical understanding and essential 21st-century skills.

Conclusion

Implementing Project-Based Learning (PjBL) in mathematics education has proven effective in improving students' academic performance, developing 21st-century skills, including critical thinking, problem-solving, collaboration, communication, creativity, technological literacy, and student motivation in various countries, and enhancing learning motivation.

Implementing the PjBL model in mathematics involves a series of well-defined steps: presenting problems, preparing project plans and schedules, forming effective teams, providing support, integrating with the curriculum, using visual media, presenting and evaluating results, and reflecting on the process. PjBL facilitates the connection between mathematical theory and its practical applications, helping students see the relevance of mathematics in real life. Studies from various countries, including Finland, Serbia, Spain, Russia, and Indonesia, show positive results from implementing project-based learning (PjBL) in mathematics education. This indicates that project-based learning (PjBL) can be adapted and is effective in various cultural contexts and educational systems. Various learning theories, including constructivism, social learning, experiential learning, multiple intelligences, contextual learning, motivation theory, and problem-solving, support PjBL. The integration of these theories explains the effectiveness of PjBL in developing mathematical understanding and broader skills. Although effective, implementing Project-Based Learning (PjBL) faces challenges such as inflexible schedules, more professional skills among teachers, and adequate resources. This indicates the need for systematic support and professional development for teachers. PjBL offers a more holistic approach to learning mathematics, allowing for the development not only of conceptual understanding but also skills such as teamwork, independent learning, and complex problem-solving. Further research is needed to optimize the integration of Project-Based Learning (PjBL) with traditional teaching methods, address implementation challenges, and analyze the long-term impact of PjBL on students' understanding and retention of mathematical concepts.

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