Teaching Mathematics Through Project-Based Learning in K-12 Schools: A Systematic Review of Current Practices, Barriers, and Future Developments

Hang Thi My Nguyen [1], Giang Thi Chau Nguyen [1], Lam Thi Hong Thai [1], Dung Thi Truong [1], Bich Ngoc Nguyen [1]

[1] *College of Education, Vinh University, Vinh, Nghe An, Vietnam*

Abstract **– Project-based learning has gained significant attention in the field of education, particularly in K-12 Mathematics education, due to its potential for fostering students' abilities relevant to the demands of the 21st century. However, there is a notable absence of a systematic evaluation regarding the implementation and effectiveness of project-based learning specifically in the context of Mathematics education. This knowledge gap presents a challenge and limitation for researchers seeking to stay abreast of the latest advancements in the field. Thus, the objective of this article is to provide a comprehensive assessment of the current state of project-based learning in K-12 Mathematics, encompassing its practices, influencing factors, barriers, and future developments. To achieve this, the study employs the PRISMA method, analyzing a collection of 25 publications retrieved from reputable databases such as Scopus and Google Scholar, covering the period from 2019 to 2023. Through meticulous analysis and synthesis of these publications, the study highlights key findings, publication trends over time, countries where project-based learning has been implemented, extracted keywords, research methodology statistics, and provides insights into influencing factors, limitations, difficulties, and future research opportunities in this domain.**

Keywords **– Project-based learning, mathematics education, trends, influential factors, limitations, research directions.**

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Corresponding author: Giang Thi Chau Nguyen,
College of Education, Vinh University, Vinh, Nghe An, Vietnam
Email: chaugiang76dhv@gmail.com

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1. Introduction

Developing 21st-century competencies is imperative and of utmost significance for learners in contemporary society [1]. Mathematical competency, encompassing proficiencies in comprehension, communication, collaboration, problem-solving, critical thinking, and creativity, stands as a pivotal skill set demanded in the 21st century [2]. Furthermore, education - in conjunction with the pre-existing attributes - plays a crucial role in cultivating and enhancing these skills among learners, making a significant contribution to the evolution and advancement of human civilization [2]. Mathematics plays a pivotal role as a solid foundation for the development of modern technology, serving as a tool subject across various disciplines and significantly contributing to the enhancement of human cognitive capacity [3]. In order to create a dynamic, collaborative environment that boosts student confidence, project-based learning emerges as a commendable choice and is recommended as an important teaching strategy within the general education program [4].

Project-based learning is a sophisticated instructional approach wherein students assume a central role in the educational process.

Guided by the teacher, learners actively engage in goal-setting, collaboration, communication, and reflection, all while tackling genuine real-life situational tasks [5].

Project-based learning empowers students to engage in critical procedures such as planning, decision-making, and creativity, ultimately fostering effective problem-solving skills. Consequently, it stands as an impactful instructional model [6]. By employing project-based teaching, educators can effectively transform students' attitudes towards learning. This approach serves as a viable alternative to the conventional instructor-centered teaching paradigm, offering a dynamic learning experience [7]. In addition, project-based learning entails engaging students in communication, collaboration, reasoning, and problem-solving endeavors, enabling them to autonomously construct their learning and create meaningful artifacts [8].

In addition to nurturing academic knowledge and comprehension, project-based teaching endeavors to facilitate the acquisition of vital 21st-century proficiencies among students. During project implementation, collaborative student groups are formed, fostering opportunities for effective communication and cooperation as they collectively tackle the assigned challenge. Within the framework of project-based teaching, students actively engage in activities encompassing presentation, inquiry, critical thinking, response, and reflective questioning, thereby fostering an environment conducive to the practical application of knowledge and skills [9], [10]. Consequently, these student-driven endeavors minimize passivity [11] and unlock the potential for cultivating essential 21st-century competencies, including effective communication, collaborative aptitude, problem-solving acumen, creative thinking, and critical analysis [12], [1].

In the realm of mathematics education, the adoption and implementation of project-based teaching are regarded as having significant potential due to the plethora of opportunities it presents to actively engage students in the learning process [13]. Facilitating the growth of students' mathematical knowledge, proficiency, scientific literacy, and 21st-century skills stands as a crucial objective within the context of project-based teaching in mathematics education [4], [14], [7], [15], [16], [17], [18], [19], [13], [1], [20], [21], [22], [23]. The literature showcases various publications that highlight the positive impact of project-based teaching models on enhancing student learning outcomes [24], [25], [19], [26], [7]. Table 1 provides a succinct overview of articles published between 2019 and 2023, which delve into the realm of project-based teaching in high school mathematics.

Table 1. Summary of articles on project-based teaching in high school mathematics (2019-2023)

Research Focuses	References
Enhancing students' mathematical proficiency through project-based teaching.	[14], [7], [15], [16], [17], [18], [19] [13], [27], [2], [23].
Factors influencing the implementation of project-based teaching in mathematics.	[28], [2], [29], [30], [31], [14], [17], [30].
Fostering 21st-century skills such as communication, collaboration, problem-solving, creativity, and critical thinking through the integration of project-based teaching in Mathematics education.	[1], [20], [21], [22], [23], [3].
Integration of project-based teaching with other instructional models and support tools.	[20], [32], [33], [22].
Development of learning materials to support project-based teaching in mathematics.	[27], [34], [10], [20].
Teachers' perceptions of project-based teaching in mathematics.	[29], [31], [4], [31].
Analysis of the application of the project-based teaching model in mathematics and students' perspectives.	[30].

Table 1 illuminates the diverse and expansive landscape of research endeavors pertaining to project-based teaching in K-12 school mathematics. The research topics within the realm of project-based teaching exhibit a wide range of diversity and comprehensiveness. The predominant research trajectory centers around the cultivation of mathematical proficiency and the acquisition of 21st-century skills. While some evaluative and literature synthesis studies have been conducted to address the aforementioned areas of inquiry, these studies predominantly focus on assessing the efficacy of project-based teaching in enhancing students' mathematical abilities within a national context. Specifically, they delve into the comparative analysis between project-based teaching and traditional instructional approaches, evaluating the impact of project-based teaching on students' mathematical aptitude across various educational levels [3], [2], [5]. The primary objective of this research article is to conduct a comprehensive evaluation of scholarly publications on project-based teaching in K-12 school mathematics, encompassing an analysis of emerging trends, influential factors, inherent limitations, and current research trajectories. This scholarly pursuit represents a distinctive and scientifically valuable contribution to the field.

More specifically, the article endeavors to address the following research inquiries: i) What are the prevailing research methodologies and recent research domains pertaining to project-based teaching in K-12 school mathematics? (RQ1); ii) Which factors exert influence on the implementation of project-based teaching in K-12 school mathematics? (RQ2); iii) What are the existing limitations in the body of research on project-based teaching in K-12 school mathematics? (RQ3); iv) In which specific areas does project-based teaching in K-12 school mathematics necessitate further exploration? (RQ4).

The identified research gaps in project-based teaching in K-12 school mathematics, as highlighted earlier, encompass crucial issues that demand attention and resolution. The endeavor to address these gaps holds significant importance. Firstly, it allows researchers to concentrate their efforts on specific salient characteristics, bypassing the need to navigate an extensive corpus of literature. Secondly, it empowers new researchers to evaluate current areas of interest and leverage the experiences and insights of preceding scholars. Thirdly, it facilitates the identification of future research directions based on the proposed concepts. Additionally, it furnishes policy planners with indicators to formulate strategies, plans, and budgetary allocations for research endeavors pertaining to project-based teaching in K-12 school mathematics.

Subsequently, this article will provide a comprehensive account of the research methodology, outlining the meticulous procedures employed in the search, collection, organization, and analysis of data.

2. Methods

In this study, the systematic evaluation employed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method [35]. The adoption of the PRISMA method serves the purpose of facilitating convenient and efficient reporting of scientific assessments and synthesis for researchers, educators, and teachers. PRISMA offers a widely accepted standardized approach through the utilization of a checklist-based guideline, which was strictly adhered to in this study [36]. This adherence ensures the quality of the revision process and enhances its replicability. The study followed a sequential procedure, including describing the inclusion criteria of the studies, elucidating the selection of literature sources, outlining the search methodology, assessing the eligibility of the studies, and concluding with the extraction and analysis of the data [36]. The PRISMA method has previously been employed to achieve similar research objectives in other studies [37], [38], [39], [40].

2.1. Eligibility Criteria

In evaluating the validity, applicability, and comprehensiveness of the assessment, the inclusion criteria play a crucial role [41]. The selected articles in this study adhere to the following inclusion criteria: Firstly, the article must include the term "project-based teaching" along with one of the terms such as "mathematics," "geometry," "algebra," "calculus," "number theory," "probability," or "statistics" in its title. Secondly, the article must be written in English and be available in full-text. Thirdly, the article must be specifically intended for K-12 school students. Lastly, the article must be published between the years 2019 and 2023.

2.2. Source Selection

A systematic search was conducted across multiple databases, namely Scopus, Google Scholar, IEEE Xplore, Eric, Wiley Online Library, and ScienceDirect. These databases were selected based on their reputation as reliable sources of high-quality research publications in the field of educational science [42], [37], [38], [39].

2.3. Search Strategy

In the initial phase, the search was conducted for publications that included the terms "Project-Based Teaching" and "Mathematics" in their titles. Subsequently, to ensure a comprehensive and thorough search, the scope was expanded to encompass synonymous and related terms. The resulting search string was formulated as follows: 'Project-Based Teaching" AND ("Mathematics" OR "Geometry" OR "Algebra" OR "Number Theory" OR "Calculus" OR "Probability" OR "Statistics"). Applying these criteria, a total of 785 articles were identified, distributed as follows: 128 articles from Scopus, 195 articles from Google Scholar, 26 articles from IEEE Xplore, 52 articles from Eric, 234 articles from ScienceDirect, and 150 articles from Wiley Online Library. The collection of articles was compiled during the period between October 4, 2023, and October 20, 2023.

2.4. Eligibility Assessment

Due to the rigorous peer-review processes and the credibility of peer-reviewed journals, this study exclusively considered publications sourced from the databases specified in section 2.2. The article selection process encompassed three distinct stages. Firstly, a preliminary screening analysis was conducted based on the titles of the articles. Secondly, a comprehensive examination of the articles' keywords and abstracts was performed.

Lastly, a thorough analysis of the full-text content was carried out. The articles extracted during the third stage underwent a meticulous evaluation to determine their inclusion or exclusion from the research dataset. The systematic review process, following a PRISMA-like approach, is visually represented in Figure 1.

During the initial stage, a total of 785 articles were identified from the aforementioned databases. After removing duplicate articles through a title consolidation process (n = 300), 485 articles remained for further analysis.

In the subsequent stage, 400 articles were excluded based on keyword and abstract analysis, resulting in a set of 85 articles eligible for full-text examination. Following the assessment of eligibility criteria, 60 articles were subsequently excluded during the full-text analysis phase. Ultimately, only 25 publications sourced from Scopus and Google Scholar were deemed suitable for inclusion in the dataset, allowing for a more comprehensive and detailed analysis.

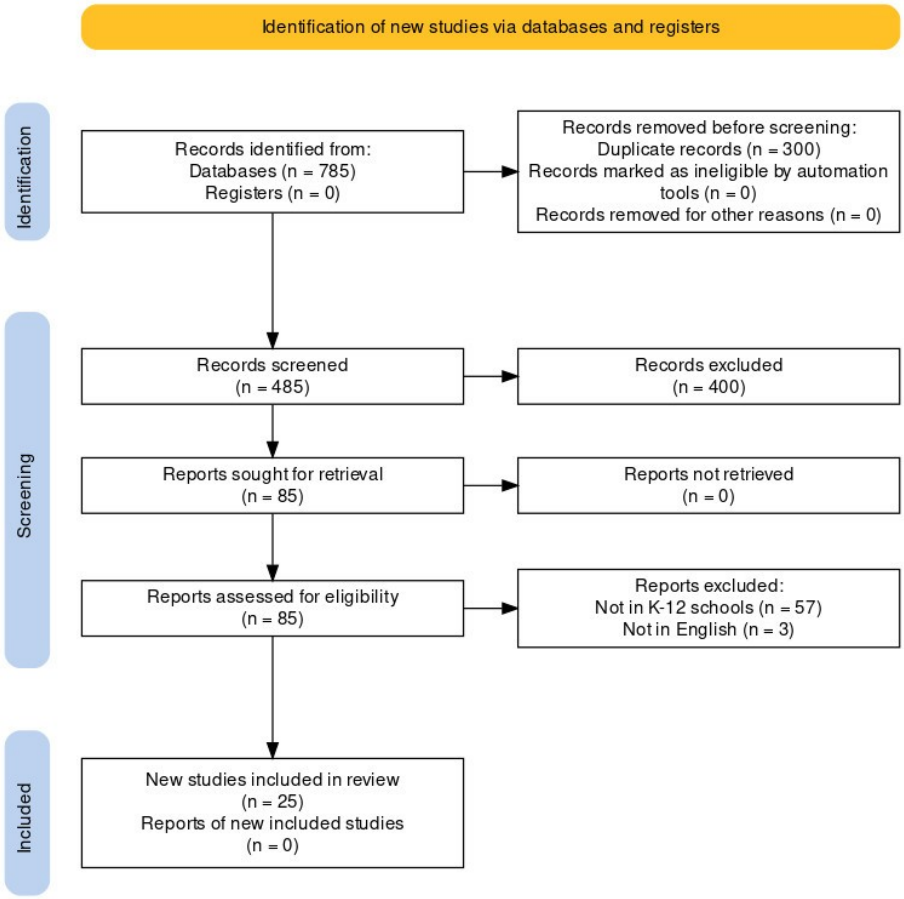

Figure 1. Research diagram depicting the data collection process at each stage

2.5. Data Encoding and Analysis

The data extraction and coding process in this study employed the MAXQDA software [43]. MAXQDA is widely recognized for its proficiency in gathering, categorizing, and analyzing qualitative or unstructured data, including interviews, evaluations, articles, and content from social media platforms and online platforms [44]. To facilitate organization and analysis, the articles pertaining to project-based teaching in mathematics at the K-12 school level were assigned unique identification codes. These codes encompassed various elements, such as the publication year, author's country, author's name, keywords, research methods, influencing factors, challenges, and research directions.

3. Results and Discussion

In this section, we present our findings with respect to each research question along with key insights.

RQ1: What are the prevailing research methodologies and recent research domains pertaining to project-based teaching in K-12 school mathematics?

Figure 2 presents a timeline illustrating the publication trends of articles related to project-based teaching in K-12 school mathematics from 2019 to 2023. During the period from 2019 to 2021, the number of articles demonstrated a consistent upward trajectory.

Specifically, in 2019, there were 5 articles, accounting for 20% of the total; in 2020, the number increased to 7 articles, representing 28% of the total.

The peak occurred in 2021, with the highest number of articles at 8, constituting 32% of the total. This notable growth can be attributed to the heightened research interest in project-based teaching during the COVID-19 pandemic. The scientific approach of this pedagogical model was deemed a fitting choice for the learning process during the crisis.

Our findings align with the conclusions drawn in [18]. In 2022, the volume of articles remained substantial, with 3 articles comprising 12% of the total. However, in 2023, a decline in research on project-based teaching in K-12 school mathematics was observed, with only 2 articles identified. This decrease can be attributed to the conclusion of our search phase on October 20, 2023, at which point some articles may have been yet to be published or made available in the databases.

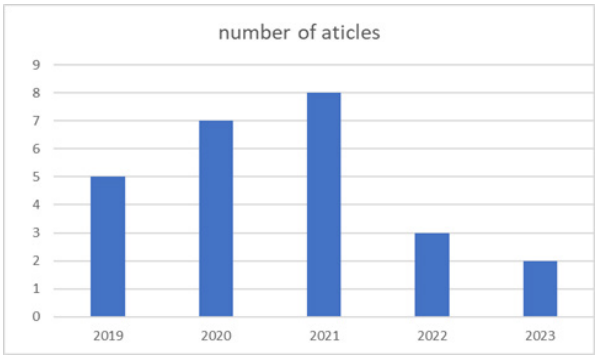

Figure 2. Project-based teaching trends in math in high schools in the period 2019-2023

Concerning the geographical distribution of the research, a noteworthy finding emerged. Out of the total articles examined, 15 (equivalent to 60%) originated from Indonesia, indicating a substantial interest within the country in conducting research on project-based teaching in mathematics. The Indonesian curriculum has introduced project-based teaching models since 2013, aligning with the demand for essential skills in the 21st century [2]. Turkey also made a significant contribution to the body of knowledge, with at least two articles dedicated to project-based teaching in K-12 school mathematics, accounting for 8% of the overall publications. The remaining eight countries each had a solitary document that focused on project-based teaching in K-12 school mathematics, as visually demonstrated in Figure 3.

Figure 3. Number of project-based teaching publications in Mathematics by country from 2019 to 2023 (n = 25)

The number of articles focusing on project-based teaching in K-12 school mathematics from Indonesia, which were included in our analysis of 25 publications, corresponds with the statistical findings derived from evaluation articles in the domains of RME education, information technology, and STEM [45], [46], [47]. Nevertheless, it is worth noting that there is a dearth of evaluation articles specifically addressing integrated education in Indonesia, as only one article [40] was identified in this area.

To explore emerging research areas, we conducted an analysis of keyword frequency in the publications. The size of each word in the word cloud [48] corresponds to its frequency of occurrence within the publications' keyword system. A total of 88 relevant terms were identified, as illustrated in Figure 4. The data derived from these terms reveals that "teaching," "project," "education," "mathematics," and "science" are the most frequently encountered terms in the articles. Close behind are terms such as "geometry," "STEM," "technology," "module," "competence," and "skills." Consequently, the key areas of focus encompass the development of mathematical competence, the cultivation of 21st-century skills, the design of project-based learning resources in mathematics, teacher awareness, integrated STEM education, and the integration of information technology.

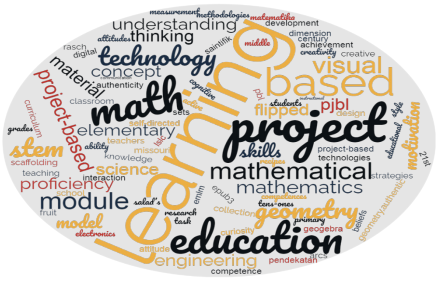

Figure 4. Featured keywords extracted from 25 articles

The design of learning resources, mathematics education, student competence, STEM education, the integration of information technology, and integrated teaching have also been highlighted in previous evaluation articles within the field of education [45], [46], [47], [40]. These findings provide additional evidence of the continuous growth of research in project-based teaching in mathematics, as it intersects with other instructional models and supportive tools, with the shared goal of enhancing student competence.

Figure 5 provides an overview of the research methods utilized in the 25 articles under examination. Quantitative research methods and mixed research methods were the most prevalent, with 7 articles (28%) each. Qualitative methods were employed by researchers in 6 articles (24%).

Additionally, 3 articles employed development research methods, while experimental methods were used in only 2 articles (8%).

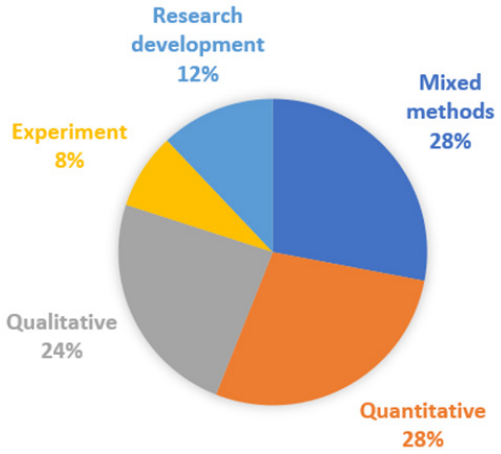

Figure 5. Percentage of research methods used in 25 articles

RQ2: Which factors exert influence on the implementation of project-based teaching in K-12 school mathematics?

Through the analysis of the publications, a wide range of factors influencing project-based teaching in K-12 school mathematics were identified. These significant findings are comprehensively presented in Table 2 as below.

Table 2. Factors affecting project-based teaching in K-12 school mathematics

No	Factor(s)	References
1	Student motivation, interest, attitudes, engagement and beliefs	[28], [30], [15], [7], [19], [17], [27], [22], [18], [1], [14]
2	Teachers' awareness and abilities	[15], [2], [30], [4], [22], [27], [31], [22], [32]
3	Learning materials	[10], [27], [16], [1], [34], [18], [7], [4]
4	Facilities, teaching aids and finances	[30], [10], [17], [1], [34], [4], [31], [18], [3
5	Timing, time allocation, schedule flexibility	[1], [2], [31], [16], [22], [4]
6	Students' mathematical ability	[10], [2], [34]
7	Motivation, interest, level of dedication of teachers	[29], [4]
8	Local factors	[31], [1]
9	Others	[28], [31], [28]

Table 2 provides an overview of the distinct categories of factors that influence project-based teaching in K-12 school mathematics. These categories have been derived from a comprehensive analysis of 25 publications. The factors have been organized into nine quantified and descendingly ordered groups, which are as follows: student motivation, interest, attitude, interaction, and confidence; teacher awareness and competence; learning materials; infrastructure, instructional resources, and financial aspects; time, time allocation, and schedule flexibility; student mathematical ability; teacher motivation, interest, and dedication; local factors; and other factors (which are mentioned only once across the publications).

Among the factors influencing project-based teaching in K-12 school mathematics, the category encompassing student motivation, interest, attitude, interaction, and confidence emerged as the most prevalent, with 13 publications addressing this aspect. The subsequent categories of teacher awareness and competence, learning materials, and infrastructure, instructional resources, and financial aspects were also prominently represented, each appearing in 9 publications. The category of time, time allocation, and schedule flexibility received notable attention, with 6 publications exploring this area. Conversely, the categories of student mathematical ability and teacher motivation, interest, and dedication were relatively less represented, with only 2 to 3 publications focusing on these factors.

Additionally, our analysis revealed several other influential factors, including teacher workload, the nature of the subject, and the characteristics of project tasks, each of which was mentioned in a single publication.

The analysis of the 25 publications has revealed a range of influencing factors. Consequently, there is considerable potential for future research to further investigate and elucidate the extent of impact these factors have, as well as explore the intricate relationships between them. This line of inquiry holds significant promise for advancing our comprehension and knowledge in the field.

RQ3: What are the existing limitations in the body of research on project-based teaching in K-12 school mathematics?

Table 3 presents a comprehensive overview of the barriers, limitations, difficulties, and challenges encountered in research pertaining to project-based teaching in K-12 school mathematics.

Table 3. Limitations of research on project-based teaching in K-12 school mathematics

No	Limitations	References
1	The experimental sample lacks diversity.	[29], [49], [1], [17], [4], [7], [10], [32], [34]
2	The size of the experimental sample is insufficient.	[28], [16], [22], [17], [4], [7], [19], [33]
3	Teachers' competence in project-based teaching is inadequate.	[18], [22], [31], [30], [4]
4	The effectiveness of the research can only be determined after experimentation, without considering long-term impacts.	[16], [22], [1]
5	tudents' experience working in groups during experiments is limited.	[30], [28], [21]
6	The authenticity of project tasks has not been thoroughly researched.	[16], [20]
7	There is a lack of systematic research on the impact of influencing factors on project-based teaching in mathematics.	[29]
8	The integrity and validity of survey content cannot be fully controlled.	[33]
9	The experimental samples may not be equivalent in terms of competency and awareness levels.	[17]

Out of the 25 publications analyzed, a substantial majority of 19 (76%) acknowledged limitations within their respective studies, while 6 publications did not explicitly outline any constraints. Notably, the issues of sample diversity and sample size received considerable attention, with 9 and 8 publications, respectively, addressing these concerns. Moreover, a significant number of studies, totaling 5 publications, highlighted the limitation of teachers' competence in implementing experimental teaching approaches. Additionally, limitations pertaining to the immediate determination of research effectiveness after experimentation and the limited experience of students working in groups during experiments were identified in 3 publications. Furthermore, two publications specifically addressed the insufficiency of research concerning the authenticity of project tasks. Furthermore, several other limitations were mentioned, with each limitation being discussed in a solitary publication.

The study systematically measured and classified the limitations in a descending order of significance. Through its research findings, it offers valuable insights into the constraints and challenges associated with project-based teaching research in mathematics.

Moreover, it paves the way for new directions of inquiry, aiming to bridge the existing gaps in knowledge and understanding.

RQ4: In which specific areas does project-based teaching in K-12 school mathematics necessitate further exploration?

Out of the 25 publications reviewed, 15 (58%) put forth recommendations for future research directions. These insightful directions have been meticulously compiled and summarized in Table 4, as presented below:

Table 4. Future research directions suggested by previous articles

Topic	Future research directions	References
The impact of project-based teaching on student ability	Investigate the influence of project-based teaching on the development of student thinking and capacity.	[17]
	Examine the feasibility and effectiveness of implementing project-based teaching across diverse subjects, grade levels, and cultural contexts.	[32]
	Explore the relationship between student academic achievement, as measured by learning goals, in the context of project-based teaching.	[4]

	Determine the most effective approach to fostering positive attitudes towards learning mathematics through project-based teaching.	[7]
	Conduct research on project-based learning in mathematics with the aim of enhancing students' higher-order mathematical thinking skills.	[3]
	Assess the impact of project-based teaching, along with other learning models, on various domains of knowledge and skills.	[19]
	Evaluate the effects of implementing a STEM-based project-based teaching model in mathematics on students' motivation to learn and creative thinking abilities across different classrooms and grade levels.	[32]
	Investigate the impact of the project-based learning model in mathematics on the development of mathematical skills.	[23]
The relationship between factors affecting project-based teaching	Investigate the correlation between interactive factors and students' learning motivation.	[28]
	Examine the distinctions between offline and online interactions among students.	[28]
	Explore strategies for fostering and sustaining student motivation in diverse learning environments.	[28]
	Develop methodologies for assessing students' learning motivation from a multidimensional perspective.	[28]
	Analyze the impact of students' awareness of project-based teaching on their academic achievement.	[4]
Scale of the studies	Conducting further research with a larger sample size would enhance the validity of the current study's findings.	[28], [16], [22], [17], [4], [7], [19], [33]
	The research provides evidence supporting the sustained effectiveness of project-based teaching over the long term.	[16], [22], [1]
	There is a need for the redevelopment of the Rasch measurement model in the field of mathematical research and other related domains.	
	Evaluate the effectiveness of project-based teaching by including a diverse sample comprising students from various educational levels and teachers from different subject areas.	[29], [16], [1], [17], [4], [7], [10], [32], [34]
	Investigate the impact of AR technology implementation in project-based classrooms by examining factors such as the size of AR devices and the number of users within a group.	[22]
Improve teacher capacity	Investigate the impact of current policies on teachers' subject expertise and propose appropriate policies for project-based teaching in K-12 schools.	[4]
	Conduct a survey to determine the statistical significance of teachers' experience in project-based teaching.	[31]
	Conduct research to evaluate the criteria for assessing teachers' digital competence	[29]
Teacher training policies	Conduct research to identify the optimal conditions for implementing project-based teaching.	[1]
	Conduct research on regular training programs for teachers in project-based teaching.	[29]
Teaching aids and learning materials	Construct comprehensive guidance materials for teachers to effectively implement project-based teaching in mathematics across various educational contexts, including different types of schools, grade levels, and age groups.	[7], [10], [34]

The findings presented in Table 4 reveal a notable research focus on delving into the profound effects of project-based teaching in mathematics on students' learning outcomes. These outcomes encompass shifts in learning attitudes [7], the cultivation of critical thinking skills [17], skill enhancement, competency development, and academic achievement [4],[3], [23],[4], [19], [32].

Moreover, researchers have advocated for in-depth investigations into the factors that influence project-based teaching in mathematics and the intricate interplay between these factors [4], [28].

The limitations identified in previous studies [29], [49], [1], [17], [4], [7], [10], [32], [34] [28], [16], [22], [19], [33] highlight research directions for new scholars. These limitations primarily revolve around the lack of diversity in experimental samples and insufficient sample sizes. As a result, numerous research avenues have been proposed to address these issues, particularly in terms of sample scale. The recommendations put forth in eight publications [28], [16], [22], [17], [4], [7], [19], [33] underscore the importance of conducting more comprehensive and in-depth studies with larger sample sizes to enhance the validity of current research findings. Furthermore, there is a consensus among researchers [29], [16], [1], [17], [4], [7], [10], [32], [34] that more inclusive research is needed to evaluate the effectiveness of project-based teaching. This involves incorporating diverse samples that encompass different educational levels and teachers from various subjects. The publications [16], [22], [1] specifically propose investigating the sustainability and effectiveness of project-based teaching to provide further confirmation.

The competence and commitment of teachers have been identified as key limitations when it comes to implementing project-based teaching [18], [22], [31], [30], [4].

Enhancing these factors is critical for the effective execution of project-based teaching strategies in mathematics.

Researchers have recognized the need for studies that evaluate standardized criteria for assessing teachers' digital proficiency [29], investigate the impact of existing policies on teachers' subject knowledge, and propose suitable policies for project-based teaching in primary and K-12 schools [4]. Implementing appropriate policies for project-based teaching in educational institutions can enhance teachers' motivation and dedication.

Furthermore, researchers have focused on investigating teacher training policies in this domain. Studies are necessary to identify the optimal conditions for integrating project-based teaching in mathematics into primary and K-12 schools [1]. Additionally, research is required to develop periodic training plans specifically tailored to teachers engaging in project-based teaching [29].

Moreover, research directions have been proposed to develop instructional materials that provide guidance to teachers implementing project-based teaching in mathematics across various contexts [7], [10], [34].

4. Conclusion

This research provides a comprehensive evaluation of project-based teaching of mathematics in K-12 schools by analyzing and synthesizing 25 publications. The study examines current practices, influencing factors, barriers, and future developments in this area. Between 2019 and 2021, the number of publications on this topic increased, with a peak of eight publications in 2021. Among the 10 countries included in the analysis, Indonesia had the highest number of publications. The frequently extracted terms, such as "teaching," "project," "education," "mathematics," "science," "geometry," "STEM," "technology," "module," "competence," and "skills," indicate research focus areas such as developing mathematical competence, fostering 21st-century skills, designing learning resources, integrating STEM education, and leveraging information technology.

The research primarily utilized quantitative research methods, with limited use of experimental and developmental research methods.

Nine categories of factors influencing project-based teaching in mathematics were identified, ranked in descending order of significance. These factors include student motivation, interest, attitude, interaction, and confidence; teacher awareness and competence; learning materials; physical infrastructure, teaching resources, and financial support; time, time allocation, and schedule flexibility; student mathematical ability; teacher motivation, interest, and dedication; local factors; and other factors that occurred in a single publication.

The findings also reveal nine limitations in the research on project-based teaching in mathematics in K-12 schools. These limitations are ranked in descending order and include a lack of diversity in experimental samples, insufficient sample size, teacher inadequacy in project-based teaching, delayed determination of research effectiveness due to the experimental nature of the studies, limited experience of students in teamwork, insufficient investigation into the authenticity of project tasks, lack of systematic longitudinal analysis of the impact of various factors on project-based teaching, researchers' inability to control the integrity and validity of survey content, and potential inequivalence of experimental samples in terms of ability and awareness.

Based on these diverse findings, future research opportunities can be categorized into six distinct groups.

These categories include studying the impact of project-based teaching on student competence, exploring the interrelationship among factors influencing project-based teaching, considering the scale of research, enhancing teacher competence, examining teacher training policies, and focusing on teaching resources and learning materials. Researchers can utilize this classification to identify suitable research directions. By moving away from studying individual factors in isolation, this classification provides a foundation for investigating and proposing policies and plans in these broad domains.

References:

[1].Rehman, N., et al. (2023). Fostering twenty-first century skills among primary school students through math project-based learning. *Humanities and Social Sciences Communications*, *10*(1), 1-12. Doi: 10.1057/s41599-023-01914-5

[2].Yunita, Y., et al. (2021). The effectiveness of the Project-Based Learning (PjBL) model in students' mathematical ability: A systematic literature review. *Journal of Physics: Conference Series.* Doi: 10.1088/1742-6596/1882/1/012080

[3].Fisher, D., Y. Kusumah, and J. Dahlan. (2020). Project-based learning in mathematics: A literatur review. *Journal of Physics: Conference Series,* Doi: 10.1088/1742-6596/1657/1/012032

[4]. Viro, E., et al. (2020). Teachers' perspectives on project-based learning in mathematics and science. *European Journal of Science and Mathematics Education, 8*(1), 12–31.

[5]. Kokotsaki, D., V. Menzies, and A. Wiggins. (2016). Project-based learning: A review of the literature. *Improving schools*, *19*(3), 267-277. Doi: 10.1177/1365480216659733

[6]. Thomas, J.W. (2000). A Review of Research on Project-Based learning in www.bobpearlman.org/BestPractices. *PBL_Research*. [accessed: 10 January 2024].

[7]. Rehman, N., et al. (2023). Altering Students' Attitude towards Math Learning Through Project-Based Learning: A Math Project. *Research Square*. Doi: 10.21203/rs.3.rs-2692214/v1

[8].Sahin, A. (2013). STEM project-based learning: Specialized form of inquiry-based learning. *STEM Project-Based Learning: An Integrated Science, Technology, Engineering, and Mathematics (STEM) Approach*, 59-64. Doi: 10.1007/978-94-6209-143-6_7

[9].Hadiyanti, N. F. D., Prihandoko, A. C., Murtikusuma, R. P., Khasanah, N., & Maharani, P. (2021). Development of mathematics e-module with STEM-collaborative project based learning to improve mathematical literacy ability of vocational high school students. In *Journal of Physics: Conference Series*, *1839*(1), 012031. IOP Publishing.

[10].Hutapea, M. and A.A. Manurung. (2022). The Development of Mathematics Learning Modules Using Project-Based Learning Models on the Material of Sets in Junior High School. *Al'Adzkiya International of Education and Sosial (AIoES) Journal*, *3*(1), 99-106.

[11]. Kimsesiz, F., E. Dolgunsöz, and M.Y. Konca. (2017). The Effect of Project Based Learning in Teaching EFL Vocabulary to Young Learners of English: The Case of Pre-School Children. *International Journal of Languages' Education and Teaching, 5(4), 426-439*. Doi: 10.18298/ijlet.2168

[12]. Bell, S. (2010). Project-based learning for the 21st century: Skills for the future. *The clearing house*, *83*(2), 39-43. Doi: 10.1080/00098650903505415

[13]. Serin, H. (2019). Project based learning in mathematics context. *International Journal of Social Sciences & Educational Studies*, *5*(3), 232-236. Doi: 10.23918/ijsses.v5i3p232

[14]. Rakhim, A.A., K. Kartono, and S. Supriyadi. (2021). Concept Understanding Skill of 8th Grade Junior High School Students in Missouri Mathematics Project Learning Based Curiosity With Scaffolding. *Unnes Journal of Mathematics Education Research*, *10*, 76-82.

[15]. Djam'an, N. (2021, May). Developing students' creativity in building city mathematics through project based learning. In *Journal of Physics: Conference Series*, *1899*(1), 012147. IOP Publishing. Doi: 10.1088/1742-6596/1899/1/012147

[16].Bowen, B.D. & B. Peterson. (2019). Exploring authenticity through an engineering-based context in a project-based learning mathematics activity. *Journal of Pre-College Engineering Education Research (JPEER), 9*(1). Doi: 10.7771/2157-9288.1073

[17]. Ubuz, B. and Y. Aydınyer. (2019). Project-based geometry learning: Knowledge and attitude of field-dependent/independent cognitive style students. *The Journal of Educational Research*, *112*(3), 285-300. Doi: 10.1080/00220671.2018.1502138

[18].Rahmawati, A.D., D.H. Supriyanto, and W.R. Sari. (2021). Project-Based Learning Model with A Scientific Approach to Mathematics Learning in Covid-19 Pandemic. *Al-Ishlah: Jurnal Pendidikan*, *13*(1), 769-775.

[19].Supriadi, N., et al. (2018). The utilization of project based learning and guided discovery learning: Effective methods to improve students' mathematics ability. *Al-Ta Lim Journal*, *25*(3), 261-271. Doi: 10.15548/jt.v25i3.487

[20].Ramalis, T. and I. Suwarma. (2020). Profile of students' critical thinking ability in project based learning integrated science technology engineering and mathematics. J*ournal of Physics: Conference Series*, *1521*. Doi: 10.1088/1742-6596/1521/2/022042

[21].Rahayu, P. T., & Putri, R. I. I. (2021). Project-Based Mathematics Learning: Fruit Salad Recipes in Junior High School. *Journal on Mathematics Education*, *12*(1), 181-198.

[22]. Mailizar, M. and R. Johar. (2021). Exploring the potential use of GeoGebra augmented reality in a project-based learning environment: The case of geometry. *Journal of Physics: Conference Series*, *1882*. Doi: 10.1088/1742-6596/1882/1/012045

[23]. Pratiwi, G., et al. (2020). The Influence of Project-based Learning (PjBL) and Learning Style om Mathematics Communication Skills of Junior High School Students. *Journal of Physics: Conference Series*, *1467*. Doi: 10.1088/1742-6596/1467/1/012064

[24]. Kristanti, Y.D. and S. Subiki. (2017). Model Pembelajaran Berbasis Proyek (Project Based Learning Model) pada Pembelajaran Fisika Disma. *Jurnal Pembelajaran Fisika*, *5*(2), 122-128.

[25]. Wahyu, R. (2016). Implementasi model project based learning (pjbl) ditinjau dari penerapan kurikulum 2013. *Jurnal Tecnoscienza*, *1*(1), 49-62.

[26]. Sunyoung, H., et al. (2016). The effect of science, technology, engineering and mathematics (STEM) project based learning (PBL) on students' achievement in four mathematics topics. *Journal of Turkish Science Education*, *13,* 3.

[27]. Ramadhani, R. & Y. Fitri. (2020). A Project-based learning into flipped classroom for ePUB3 electronic mathematics learning module (eMLM)-based on course design and implementation. *Universal Journal of Educational Research*, *8*(7), 3119-3135.

[28]. Kim, H.W. and M.K. Kim. (2021). A Case Study of Children's Interaction Types and Learning Motivation in Small Group Project-Based Learning Activities in a Mathematics Classroom. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(12).

[29]. Hossein-Mohand, H., et al. (2021). Analysis of the use and integration of the flipped learning model, project-based learning, and gamification methodologies by secondary school mathematics teachers. *Sustainability*, *13*(5), 2606. Doi: 10.3390/su13052606

[30]. Doğan, Z. and B. Karabulut. (2019). Analyzing the process of using project-based learning method in teaching the concept of tens-ones in elementary math course. *Universal Journal of Educational Research*, *7*(4), 1120-1128. Doi: 10.13189/ujer.2019.070424

[31]. Tarasenkova, N., et al. (2020). Characteristics of Mathematics Teachers' Practices and Beliefs about Project-based Learning and Teaching Mathematics in Ukraine. *Universal Journal of Educational Research,* (8), 7631-7642. Doi: 10.13189/ujer.2020.082549

[32]. Surmilasari, N. and H. Usman. (2022). Creative thinking with stem-based project-based learning model in elementary mathematics learning. *Jurnal Pendidikan Dasar Nusantara*, *7*(2), 434-444. Doi: 10.29407/jpdn.v7i2.17002

[33]. Wahyuningsih, S., et al. (2021). The Effect of Online Project-Based Learning Application on Mathematics Students' Visual Thinking Continuum in Covid-19 Pandemic. *International Journal of Interactive Mobile Technologies*, *15*(8). Doi: 10.3991/ijim.v15i08.21565

[34]. Hutapea, M. (2022). Development of Mathematics Learning Modules Using Project Based Learning Models on the Subjects of the Junior High School Association. *Jurnal Riset Ilmu Pendidikan*, *2*(2), 72-77.

[35]. D. Moher, D.G.A., A. Liberati, và J. Tetzlaff. (2011). "PRISMA statement". *Epidemiology*, *22*(1), 128. Doi: 10.1097/EDE.0b013e3181fe7825

[36]. Moher, D., et al. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic reviews*, *4*, 1-9.

[37]. Nguyen, V.T.N.v.C.T.H. (2022). A systematic review of structural equation modeling in augmented reality applications. *Indonesia Journal of Electrical Engineering and Computer Science (IJEECS)*, *28*(4), 328–338. Doi: 10.11591/ijeecs.v28.i1.

[38]. Nashir, A.I.a.I.M. (2022). Trends and patterns of needs assessments in technical and vocational education: A thematic review. *International Journal of Evaluation and Research in Education (IJERE)*, *11*(1), 88–98. Doi: 10.11591/ijere.v11i1.21940

[39]. Prasetiyo, W.H., et al. (2021). Digital Citizenship Trend in Educational Sphere: A Systematic Review. *International Journal of Evaluation and Research in Education*, *10*(4), 1192-1201. Doi: 10.11591/ijere.v10i4.21767

[40]. Nguyen, G.T.C. and D.T. Thai. (2023). Integrated teaching in primary schools: A systematic review of current practices, barriers, and future developments. *Int J Eval & Res Educ*, *12*(4), 2053-2062. Doi: 10.11591/ijere.v12i4.26087

[41]. Liberati, A., et al. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *Annals of internal medicine*, *151*(4), W-65-W-94. Doi: 10.7326/0003-4819-151-4-200908180-00136

[42]. Peixoto, B., et al. (2021). Immersive virtual reality for foreign language education: A PRISMA systematic review. *IEEE Access*, *9*, 48952-48962. Doi: 10.1109/ACCESS.2021.3068858

[43]. Rädiker, S. & Kuckartz, U. (2019). *Analyzing Qualitative Data with MAXQDA*. Springer Cham.

[44]. Gizzi, M. C., & Harm, A. (2021). Using MAXQDA from Literature Review to Analyzing Coded Data: Following a Systematic Process in Student Research. *The Practice of Qualitative Data Analysis Research: Examples Using MAXQDA*.

[45]. Phan, T. T., Do, T. T., Trinh, T. H., Tran, T., Duong, H. T., Trinh, T. P. T., ... & Nguyen, T. T. (2022). A Bibliometric Review on Realistic Mathematics Education in Scopus Database between 1972-2019. *European Journal of Educational Research*, *11*(2), 1133-1149. Doi: 10.12973/eu-jer.11.2.1133.

[46]. Trinh Thi Phuong, T., Nguyen Danh, N., Tuyet Thi Le, T., Nguyen Phuong, T., Nguyen Thi Thanh, T., & Le Minh, C. (2022). Research on the application of ICT in Mathematics education: Bibliometric analysis of scientific bibliography from the Scopus database. *Cogent Education*, *9*(1), 2084956. Doi: 10.1080/2331186X.2022.2084956.

[47]. Ha, C. T., Thao, T. T. P., Trung, N. T., Van Dinh, N., & Trung, T. (2020). A bibliometric review of research on STEM education in ASEAN: Science mapping the literature in Scopus database, 2000 to 2019. *Eurasia Journal of Mathematics, Science and Technology Education*, *16*(10), em1889. Doi: 10.29333/ejmste/8500.

[48]. Dicle, M.F. & B. Dicle. (2018). Content analysis: frequency distribution of words. *The Stata Journal*, *18*(2), 379-386.

[49]. Holmes, V.-L. & Y. Hwang. (2016). Exploring the effects of project-based learning in secondary mathematics education. *The Journal of Educational Research*, *109*(5), 449-463. Doi: 10.1080/00220671.2014.979911