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Integration Review of Project Based Learning in Biology Education: A Systematic Literature Synthesis of Education Levels, Biology Subdisciplines, Research Methodologies and Learning Competencies

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ABSTRACT
Project-Based Learning (PjBL) has become an increasingly popular learning approach in many fields, including biology. The research conducted a systematic review of the literature on the implementation and effectiveness of PjBL in biology education, especially in the period 2019–2023. The study explores the use of PjBL in various subdisciplines of biology, education, and research methodologies, as well as integrating a variety of targeted learning and competence approaches. Colleges widely adopt PjBL, focusing on developing students' cognitive, affective, and psychomotor abilities. The study also highlights the various learning methods integrated into the pjBL, including laboratory experiments, field activities, and reflection. The findings confirm that PjBL is an effective educational strategy for improving student understanding of concepts, critical thinking skills, and learning motivation. This approach supports holistic and applied learning experiences, integrating theory with real practice, as well as developing skills essential to students in the 21st century. The study provides a comprehensive insight into the current trends and potential of PjBL in biology education, as well as recommending directions for future education research and practice.

Keywords: Project-Based Learning, Biology Education, Literature synthesis

A. INTRODUCTION

Project-based learning (PjBL) has become an increasingly popular learning approach in many fields, including biology. PjBL emphasizes authentic learning experiences in which students participate actively in the learning process through significant and contextual projects (Thomas, 2000). PjBL is an approach that emphasizes student learning through complex and authentic projects that last over a certain period of time (Blumenfeld et al., 1991). In biology education, PJBL has been seen as a potential tool to enhance student understanding of concepts, critical thinking skills, and learning motivation (Geier et al., 2008). PjBL promotes student involvement in solving real problems or meaningful investigative questions (Bell, 2010). The use of PjBL in biology education opens new paths in teaching methods so that students are not only passive recipients of information but active participants in the learning process. This approach not only improves students' knowledge and skills but also builds confidence and curiosity, which are essential for their future success.

In the last decade, PjBL has experienced significant growth in implementation and research in various disciplines, including biology education. Biology is a complex subject that requires an in-depth understanding of concepts. PJBL has been used in biology education to help students understand complex concepts through investigation and exploration (Krajcik & Shin, 2014). PjBL is recognized as an approach that allows students to engage actively in the learning process, integrate knowledge from various sources, and develop 21st-century skills (Condliffe et al., 2017). The PjBL model is effective in improving student biology learning outcomes. It has a significant positive impact on student learning output. The use of the model can substantially improve students' learning output in the field of biology. This study found that PjBL not only affects biology learning results but also positively affects the development of students' creative and critical thinking skills. These skills are highly valued in contemporary and industrial education, making them important. PjBL has proven to be effective across a wide range of geographical areas, educational levels, and applications in learning biology, suggesting that it is a flexible and adaptable approach. PjBL provides a positive influence on the development of 21st century skills and knowledge or cognition in students, which affirms the importance of this approach in preparing students for future challenges. (Widarbowo et al., 2023). The effect of PjBL on science learning at all levels of education, from elementary school to university, The PjBL learning model is considered effective for science learning. With a high measure of effect, this suggests that students who follow the pjBL model are likely to show a significant improvement in their learning outcomes compared to traditional learning methods. The findings provide support for educators and educational institutions to implement or continue to use PjBL as a teaching strategy to improve scientific learning outcomes (Nurhasnah et al., 2022). The PjBL approach has the potential to make a significant contribution to improving scientific learning outcomes at various levels of education, including at the secondary school level and in physics subjects (Ayaz & Söylemez, 2015). A project-based learning application that not only supports the development of STEM education but also makes a positive contribution to public health issues by involving students and various stakeholders directly in the learning process (Santos et al., 2023). Nevertheless, there are some challenges in implementing the PJBL in the biology class, one of which is about teachers who can design and evaluate effective projects (Ertmer & Simons, 2006). In addition, literature shows that there is no consensus on what constitutes "best practice" in PjBL for biology education.

"Project-Based Learning: A Systematic Literature Review (2015–2022)," as a previous SLR study, analyzes project-based learning (PjBL) at various levels of education, especially secondary education. This review identifies significant advances in the application of PjBL, highlighting its benefits in improving students' cognitive, linguistic, social, and overall academic performance. This article emphasizes the interdisciplinary nature of PjBL and its effectiveness in encouraging active learning and creativity. The research also notes the major contribution of Spain in this field and suggests the expansion of the curriculum and the integration of PjBL into the teacher training programs. This review provides valuable insights into the development of PjBL in the context of education, encouraging greater implementation and recognition of pedagogical strategies (Hidalgo, 2022). This article presents a different approach to its research. This article conducts a systematic literature review specific to biology education. The article analyzes the subdisciplines of biology, the context of education, research methods, integration in the application of PjBL, and the competences that PjBL enhances in biology education.

In the context of biology education, PjBL has been identified as one of the strategies that can support student understanding of concepts and increase learning motivation (Hmelo-Silver et al., 2007). However, although a lot of research has been done on PjBL, there is a need to understand the latest research trends in PJBL in biology education, especially in the period 2019–2023, to evaluate developments and opportunities in this area, provide comprehensive insight into the application and effectiveness of PjBL in biological education, and provide recommendations for educational practices and future directions of research.

B. METHOD

The writer analyzes the literature thoroughly to achieve the above-mentioned goal. To reduce the likelihood of bias and errors, the value of systematic analysis relies on rigorous methodologies and clarity of reporting. This article's systematic literature review relies on the reporting items selected for systemic analysis and meta-analysis diagrams. (Liberati et al., 2009) which allows other researchers to replicate analytical procedures and the same set of data and findings (Bellucci et al., 2022; Linnenluecke et al., 2020; Paoloni et al., 2020). Here's a scheme of methods for a systematic literature review.

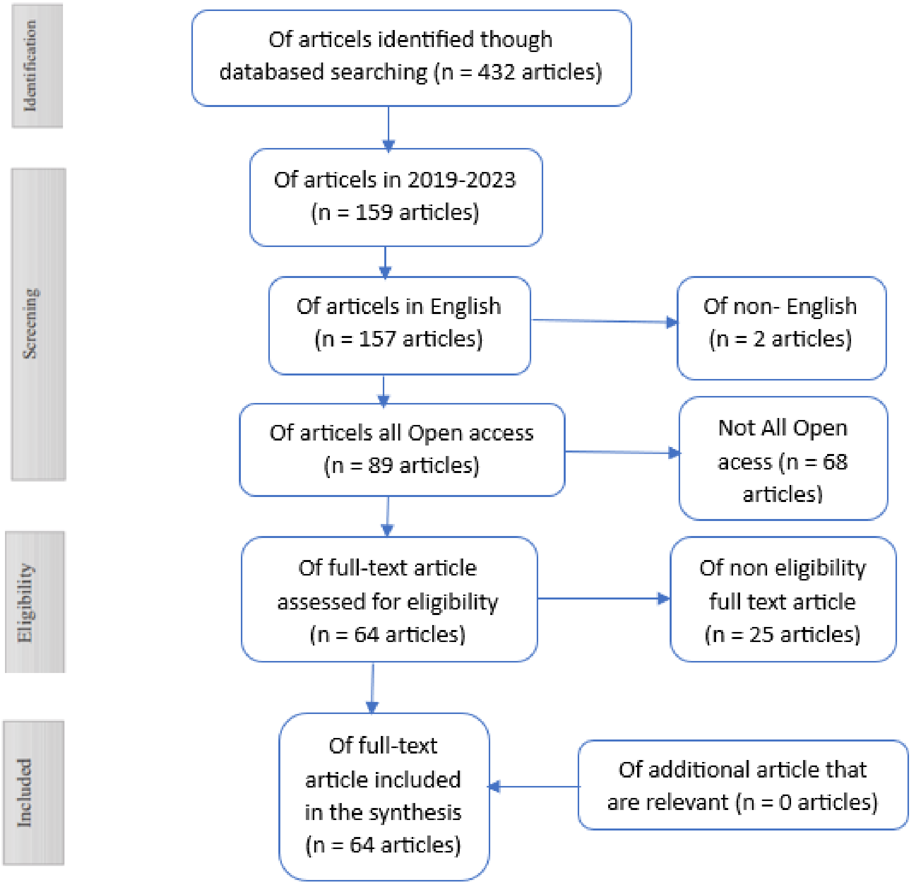

Figure 1. Source: Figure by authors based on Liberati et al. (2009)

Research questions drive a thorough review process, defining the subject, object, and scope of research. As a result, our research focuses on research questions that:

1. What are the sub-disciplines of biology in the research on the application of PjBL to biology education?
2. What is the significance of education in research on the application of PjBL to biology education?

3. Which research methods are used to apply PjBL to biology education?
4. What does the application of PjBL integrate into biology education?
5. Applying PjBL to biology education enhances which competencies?

"Project-Based Learning" and "Project-Based Learning in Biology Education" searches found 159 articles with filters for 2019–2023. The researchers deleted two non-English-language articles, so the number of articles was 157, and filtering all open access resulted in 89 articles. Next, we evaluate the relevance of the title, abstract, and contents of each article. Removed 25 articles that the researchers deemed irrelevant to the research. Next, the researchers checked the availability of full-text articles. Thus, the authors researched 64 articles..

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C. RESULT AND DISCUSSION

1. The Subdiscipline of Biology in the Application of PjBL in Biology Education

The results of the systematic review provided an overview of the application of the learning model based on PjBL in various subdisciplines of biology.

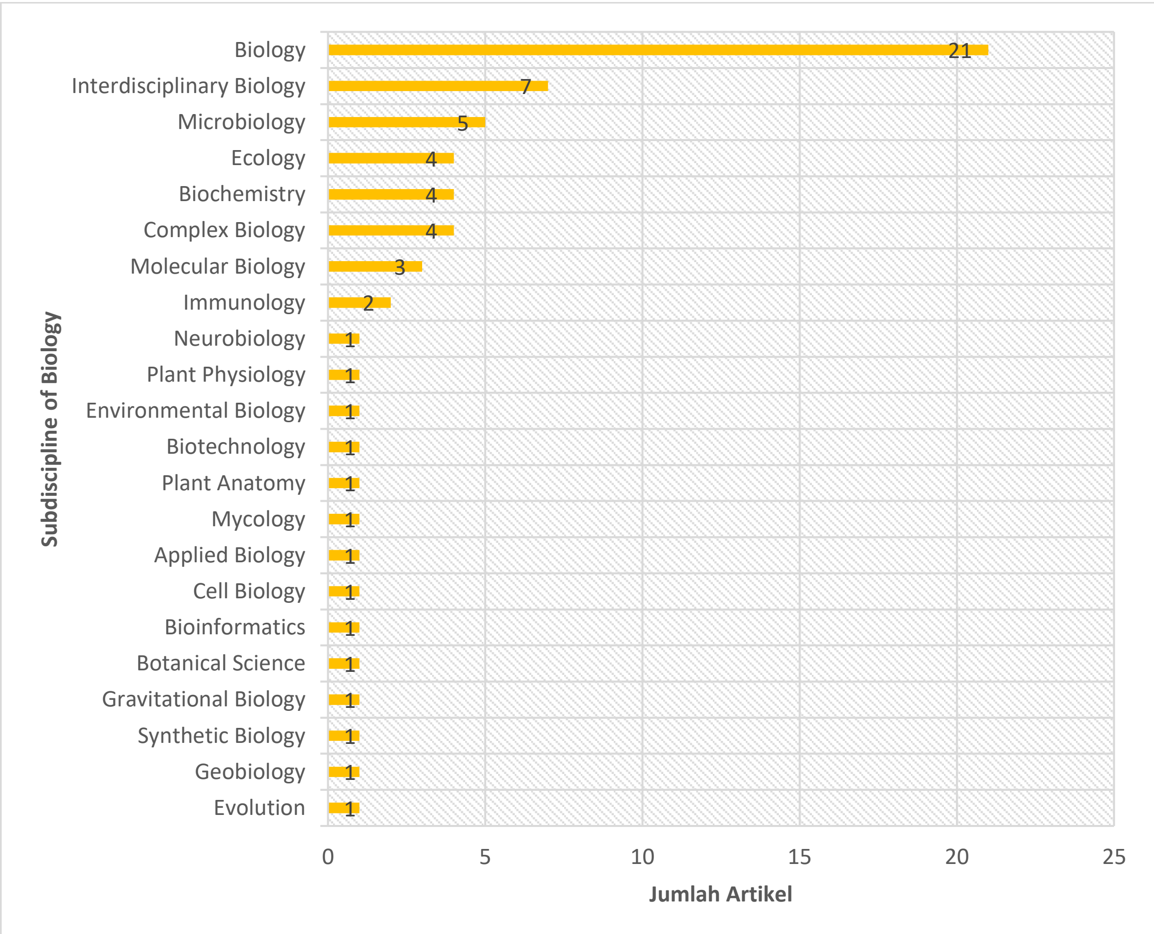

Figure 2. Subdisciplines of Biology in the Application of PjBL in Biology Education

The results of the review show that 'Biology' as a general category dominates with 21 studies. When using the PjBL learning model, researchers in the "Biology" classification do not explicitly mention the discussed biological material. Researchers in the "Biology" classification dominate educational biology research, which encompasses the development and integration of approaches, models, media, and specific methods related to the learning process. The 21 studies' biology subdiscipline description results relate to media biology topics that motivate students to create media for the learning process (Susanti et al., 2020), focused on the preliminary biology course for non-STEM students (Burks, 2022), The main focus is on scientific literacy acquired through STEM education, with biology included in the STEM concept (Ahmada et al., 2021), reforms in the biology program aim to enhance quantitative and research skills by implementing a research-based approach known as CURE in the preliminary biology laboratory course (Pavlova et al., 2021), focused on improving scientific literacy skills among students in the Department of Biological Education (Agustina, Wilyati., Degeng, I Nyoman S., Praherdhiono, Henry., Lestaric, 2023), science learning with the integration of biological content (Ortega-Torres & Moncholí Pons, 2021), biology education at the undergraduate level and the implementation of pedagogical-based research to improve the quality of learning-teaching experiences in biology (Hegde & Karunasagar, 2021), implementation of origami microscopes and foldscopes in biology education to replace expensive traditional instruments (Kulshreshtha et al., 2022), the use of active teaching methods in biology education enhances student learning (Rossi et al., 2021), communication in biology teaching should focus on improving future teacher communication skills (Lubis et al., 2020), large-scale biology research based on "big data" and networked research initiatives (Jensen-Ryan et al., 2020), focuses on the learning process of biology, with special emphasis on improving the creative thinking ability of future teachers in the context of biological learning (Yustina et al., 2020), the nutritional content of the ingredients used to make analog rice and its combinations can be better understood through the application of biological principles (Koes-H et al., 2021), The research primarily focused on mathematics, while the earlier research mentioned in the context demonstrated the impact of PjBL on science education, including biology (Susiyanti et al., 2022), focuses on biology learning and how different teaching methods affect student metacognitive awareness and cognitive learning outcomes (Ilma et al., 2022), development of a curriculum of biology education programs in line with the demands of 21st century education and the goals of Indonesian national education (Suwono, 2019), focus research on the tissue model of metabolism in integrated systems biology (Sauter et al., 2022), Biology education focuses on developing course-based undergraduate research experiences (CUREs) to promote research skills among students (Indorf et al., 2019), students' research skill formation in biology education (Salybekova et al., 2021) and Formative assessment in project-based learning has a significant impact on learning outcomes in high-level biology education (Sari et al., 2019). Research in the context of PjBL with a focus on biology shows diverse trends, from curriculum development and teaching approaches to technology integration and emphasis on scientific literature and research skills. This highlights the importance of biology as a dynamic and adaptive field of study in contemporary education.

The subdiscipline 'Interdisciplinary Biology' follows with seven studies, reflecting current trends in biological education where interdisciplinar integration is considered essential to understanding complex biological systems and real-world applications. Assessments of PjBL support learning that utilizes an interdisciplinary approach to equip students with the skills necessary to deal with contemporary challenges. The results of the biology subdisciplinary description of the seven studies are the integration of mathematics and biology in cross-discipline education (Phuong Chi, 2021), Biodiversity is the study of biodiversity through the collection and classification of ant species using field and laboratory techniques. In addition, DNA barcoding techniques are used for species identification (Bucklin & Mauger, 2022), Eco-literacy, which encompasses natural history and direct observation of the natural world and its organisms, is particularly important in understanding bird biodiversity (Collins & Donahue, 2019), student understanding of the nature of science (NOS) in the context of conservation education (Sukaesih et al., 2022), the development of talents and skills necessary to support biological-based economic growth and meet the demand for professional and research-based degree programs (Gill et al., 2022), increased representation of women and diversity in STEM (science, technology, engineering, and mathematics), including medicine, as well as the use of high-performance computing (HPC) in biomedical education. (Townsend-Nicholson, 2020) and although biology is mentioned as one of the subjects in the participating schools, the main abstract focus lies in integrating information technology and mathematics into education (Andersen et al., 2021). Research in 'Interdisciplinary Biology' shows a trend towards a more integrated and holistic approach to education, integrating a variety of disciplines to provide a richer and more applied context in the study of biology and science in general.

Five studies in 'Microbiology' demonstrate the practical relevance and importance of project-focused learning in understanding microorganisms and microbiological processes. 'Complex Biology' and 'Biochemistry' respectively represent 4 studies, underscoring the value of PJBL in facilitating understanding of more abstract and complex concepts through project-oriented learning experiences. 'Molecular Biology" and 'Ecology' each attract 3 and 4 researches, indicating that PjBL helps students understand these concepts via exploration and practical experimentation. The fact that disciplines such as immunology, neurobiology, biotechnology, and others, although only each of them is represented by one study, are included in this review shows the potential of PjBL to extend to the entire biological spectrum. Collectively, emphasize the validity of the statement about the potential of PjBL in advancing science education by providing a strong foundation for understanding and exploring the world of biology. (Markula & Aksela, 2022; Balemen & Özer Keskin, 2018). Thus, the effectiveness and versatility of PjBL in the diverse field of biology promise significant progress in science education, providing a solid foundation for future generations to understand and explore the wonders of the biological world.

These findings indicate that PjBL is widely adopted across various biological subdisciplines, particularly in the general categories of biology and interdisciplinary biology. PjBL has demonstrated significant benefits in biology education, both in improving understanding of complex concepts and in developing relevant skills. However, addressing the challenges related to the scale and sustainability of PjBB, particularly in integrating with reform-based standards, remains necessary (Movahedzadeh et al., 2012; Miller & Krajcik, 2019). This application marks a growing awareness of the effectiveness of PjBL in promoting in-depth understanding and relevant skills in specialized fields, as well as excellence in teaching more complex and integrative biological concepts.

2. Education in the Application of Project-based Learning (PjBL) in Biology Education

The systematic review analysis reveals a striking distribution in the application of the PjBL learning model across various levels of education. The figure of the number of educational levels is as follows:

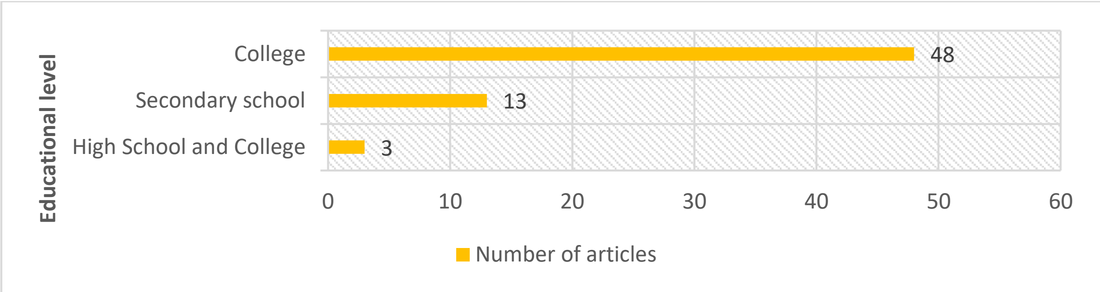

Figure 3. Education in the Application of Project-based Learning (PjBL) in Biology Education

Research results show that colleges are the most implementing environment for PjBL, with a total of 48 studies indicating its use. Meanwhile, high schools have 13 studies related to the application of PjB. Lastly, a combination of high schools and colleges has three studies recorded. This narrative highlights the significant difference in PjBL adoption between higher and secondary education. Colleges seem to be more likely to adopt PjBL, probably because of a higher degree of autonomy in curricula and academic freedom that allows for a broader exploration of innovative teaching methodologies (Prakash, 2011). On the other hand, the use of PjBL in secondary schools is quite significant, but less significant, because of limited resources, institutional support, or stricter curriculum structures that impede the implementation of flexible, project-based learning methods. However, implementing PjBL in secondary schools poses significant challenges, particularly in terms of time, standards, and resources. (Harris, 2015). Although the integration of these two forms of education into the use of PjBL is still in its early stages, it has the potential for further exploration and cross-cutting. Thus, although colleges own the largest share of the implementation of pjBL, there is significant room for growth and integration at the secondary school level, where the challenges and constraints that exist require innovative strategies and cross-country collaboration to optimize the benefits of this education.

Successful implementation of PjBL in colleges and high schools shows the potential of this learning model to facilitate active learning, enrich student experience, and develop essential skills such as problem-solving, teamwork, and communication. PjBL improves learning outcomes and student competence development in the context of online learning. (Hidayah et al., 2021). PjBL can motivate students to learn and has the potential to enhance challenging learning content as well as other skills such as problem-solving and self-confidence. This approach also takes into account the individual needs of students, thus responding to cultural, racial, socio-economic status, and gender differences. (Miller & Krajcik, 2019). The correlation between theory and practice emphasized in PjBL supports the cultivation of an in-depth and applied understanding of the material studied, an important aspect of 21st-century education.

3. Research Methods for Applying PjBL in Biology Education

Systematic review analysis of the use of the PjBL learning model provides data that demonstrates a variety of research methods applied in the studies being reviewed. Here's a figure that illustrates the results:

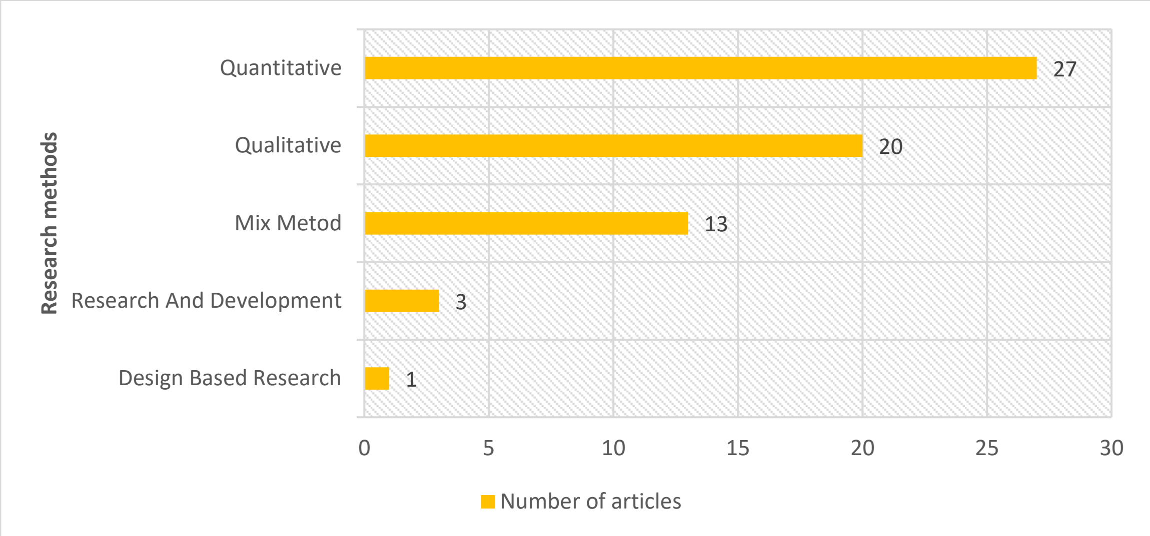

Figure 4. Research Methods for Applying PjBL in Biology Education

Researchers have explored the PjBL learning model through various research approaches in the set of analyzed studies. Quantitative becomes the most commonly used method, with 27 studies adopting this approach, showing a tendency to measure the effectiveness of PjBL with more empirical and statistical methods. Quantitative research often focuses on data that can be measured and calculated to assess learning outcomes or the effectiveness of interventions (Hagan, 2014; Clarke et al., 2019). The qualitative research conducted in 20 studies offers a comprehensive understanding of the experiences of pupils and educators with PjBL. This approach indicates that there is still a strong tendency to understand learning phenomena in a more profound and subjective context, which not only focuses on numbers and data but also on the experiences, perceptions, and responses of learners as well as educators. (Damaskinidis, 2017; Han & Ellis, 2019; Kostøl & Remmen, 2022). Collective methods enable researchers to capture the nuances and complexities of learning experiences that cannot be achieved through quantitative methods alone, providing a deeper understanding of how individuals experience and characterize learning phenomena. Therefore, the balance between quantitative and qualitative research methods in PjBL not only emphasizes the importance of measuring the effectiveness of this approach empirically but also highlights the value of subjective experience in understanding its impact on the learning process.

The mixed methods that combine the qualitative and quantitative elements used in 13 studies show an effort to integrate both the above approaches, quantitatively and qualitatively, to gain a more holistic and comprehensive understanding. Research with mixed methods can provide a richer view of how the PjBL model works in practice and what impact it has on students' learning processes and outcomes. (Noble et al., 2020). Furthermore, three studies have identified the use of the Research and Development (R&D) approach, indicating a research focus on developing and testing the PjBL learning model. This model involves design, development, and evaluation cycles to refine its effectiveness in educational practice. (Syukri et al., 2021). Meanwhile, design-based research (DBR) recorded in 1 study suggests that this approach is less often chosen by researchers. DBR usually involves iteration of design and redesign under real conditions to improve educational practice and produce learning design theory (Armstrong, M., Dopp, C., & Welsh, 2018). The whole of this research, with the application of mixed methods, research and development (R&D), and design-based research (DBR), demonstrates diversity in approaches to understanding and developing project-based learning (PjBL) models. From integrating qualitative and quantitative methods for holistic understanding to designing iterations in DBR, each method makes unique contributions to improving educational practice and the development of effective learning theory. In general, preference for quantitative and qualitative methods reflects the need to measure outcomes and comprehensively understand learning processes in PjBL applications. The findings confirm that PjBL is a dynamic research area with a variety of methodological approaches used to explore its effectiveness in education (Markula & Aksela, 2022). The invention of these research methods suggests that the research community recognizes the need for different approaches to understanding complex phenomena such as PjBL.

4. Integration of Learning Approaches in the Application of PjBL in Biology Education

However, each article has an integration focus for implementing PjBL in biological education. Findings from this systematic literature review reveal the integration of various learning approaches into the pjBL model depicted in Figure 5 as follows:

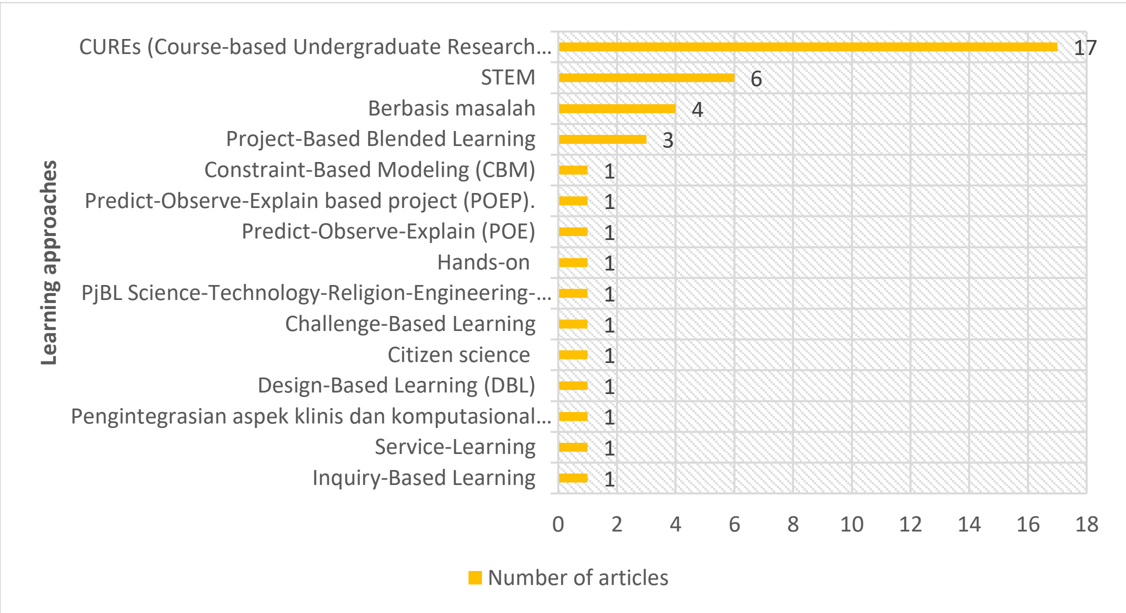

Figure 5. Integration of Learning Approaches in the Application of PjBL in Biology Education

The data on the figure 5. shows variations of learning approaches integrated into the PjBL model in biology education. CUREs (course-based undergraduate research experiences) stand out as the most frequently integrated approach, indicating that course-based research plays an important role in biological education. The importance of CUREs in providing an opportunity for students to think critically and apply students' understanding in a real context, which is a key aspect of biology education (Martin et al., 2021). The STEM approach, which refers to the integration of science, technology, engineering, and mathematics, is also quite popular, with six implementations. It affirms current educational trends that emphasize the importance of an interdisciplinary approach in STEM to prepare students with skills relevant to the 21st century (Stehle & Peters-Burton, 2019). The 'problem-based' and 'project-based blended learning' methods also recorded significant use, with 4 and 3 implementations, respectively. Both methods support inquiry-based learning and problem-solving, which promote critical thinking and the application of knowledge in real-world contexts. (Attard et al., 2021). Biological education is moving towards a more dynamic and interactive learning paradigm. Today's biology education encompasses not only the understanding of basic concepts but also their application to real-world research and problems, ranging from CUREs to problem-based learning. This initiative not only enriches student learning experiences but also prepares students for success in future careers, namely the ability to think critically and work collaboratively, which becomes increasingly important. Thus, this variation of learning approach reflects the commitment of biology education to developing students who are not only knowledgeable but also able to innovate and adapt in an ever-changing society.

Other methods such as 'Constraint-Based Modeling (CBM)', 'Predict-Observe-Explain-Based Project (POEP)', and 'P Predict-Observe-Explain (POE)' all have one implementation, suggesting that there is an exploration of innovative methods, although not as popular as other methods. Approaches such as 'Hands-on', 'PJBL Science-Technology-Religion-Engineering-Arts' (STEAM), 'Challenge-Based Learning', 'Citizen Science', 'Design-Based Learning (DBL)', 'Integrating clinical and computational aspects...', 'Service-Learning', and 'Inquiry-Based Learning' are also seen to be used once. These variations indicate that educators are constantly looking for new ways to engage students and improve learning outcomes (Herodotou et al., 2019). By introducing diverse and innovative learning approaches, educators not only enrich curricula but also demonstrate a commitment to creating in-depth and relevant learning experiences. These efforts reflect a desire to continue to adapt teaching methods to the evolving needs and interests of students, as well as prepare them to face future challenges with broader skills and knowledge.

So it can be concluded that the chart highlights the importance of integrated PjBL with a diverse and adaptive approach to education, with an emphasis on methods that drive student research and STEM integration. However, it is also important to note that although some methods are not as popular as others, variations in learning approaches indicate a commitment to innovation and the personalization of learning experiences for students.

This data provides an overview of the various learning media that are integrated in the PjBL model. Figure 6. is the integration of learning media in biology education as follows:

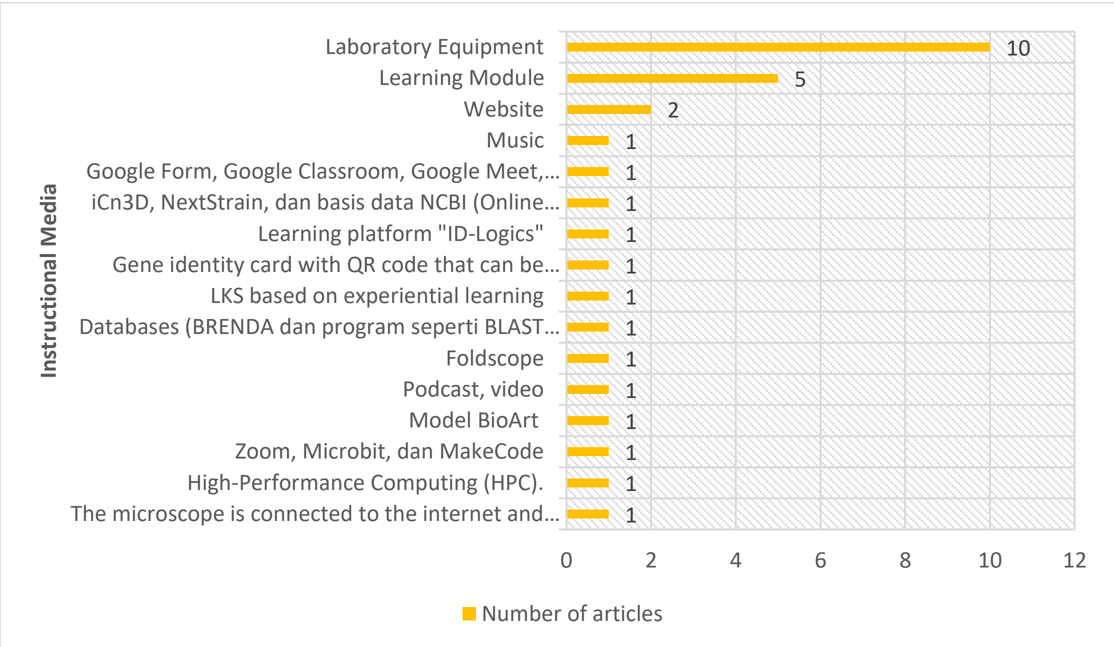

Figure 6. Integration of Learning Media in the Application of PjBL in Biology Education

In the literature exploration related to the integration of learning media in PjBL, it is seen that laboratory tools dominate with nine articles, affirming the important role of practicum and experiment in project-based education, in which students learn through practical experience (The American Chemical Society (ACS), 2020). The learning modules are quoted in five articles, showing the importance of structured materials designed to guide students through project-based learning processes and offering direction and content relevant to research (Ariefiani et al., 2016). Practical experience and structured mentoring are key components of supporting in-depth student learning. Laboratory tools and learning modules serve as essential tools that enable students to actively engage in the learning process, integrate theory with practice, and develop essential skills that they will bring into their professional and academic lives. It shows an educational movement that emphasizes not only theoretical knowledge but also the practical skills and analytical abilities of students, which are becoming increasingly important in a rapidly changing and high-tech society.

The latest technologies, such as Internet-connected and remote-controllable microscopes, as well as high-performance computing (HPC), each mentioned in one article, indicate the use of advanced tools to expand the possibilities of scientific exploration and analysis of complex data in PjBL. (Miller & Krajcik, 2019). The use of Zoom, Microbit, and MakeCode in one article reflects the adaptation of information and communication technology in PjBL, which allows for collaborative and interactive coding learning. The BioArt, podcast, and video models, also each recognized in one article, show an innovative approach to integrating art, audio, and visual media into project-based learning, which can enhance student engagement and understanding. Foldscope, a simple yet revolutionary tool, is recognized in one article as a medium that allows for low-cost scientific observation, promoting the accessibility of science. These findings demonstrate the effective use of both advanced and simple technology to enrich project-based learning experiences.

Scientific databases like BRENDA, BLAST, and Clustal Omega also got a place in one article, which states the importance of access to scientific information sources in student research. LKS-based experiential learning and gene identity cards with QR codes that can be scanned by mobile phones, each in one article, emphasizing real experience and the use of technology in the learning process. "ID-Logics" learning platforms, online tools such as iCn3D, NextStrain, and NCBI databases, along with various websites, are acknowledged in multiple articles, showcasing the wide range of digital learning resources and interactive tools available for PjBL. One article recognizes Google Forms, Google Classroom, Google Meet, and WhatsApp as classroom communication and management tools that facilitate the implementation of PjBL in more distributed and connected formats. One article also includes music, suggesting the use of unconventional media to enrich learning experiences, even if it is not directly linked to PjBL. All of this shows that by leveraging the wide range of available digital resources and tools, PjBL can become more effective, interactive, and attractive, thus expanding learning horizons and driving innovation in education.

Overall, the data demonstrates that PjBL has adapted to a variety of learning tools and resources, ranging from traditional tools to the latest digital solutions, showcasing its responsiveness to changing technology and educational methods. The importance of implementing PjBL with a focus on teaching 21st century skills, a student-centered approach, and strong personal interaction between students and teachers. Furthermore, the identification of challenges in the implementation of PjBL, including project organization and technical problems, emphasizes the importance of understanding how teachers implement PJBL and the associated challenges and opportunities in practice (Markula & Aksela, 2022). It affirms the potential of PjBL to provide a rich and multidimensional learning experience that utilizes a variety of learning media to support a holistic and integrated educational experience.

Data from this systematic literature review shows a variety of integrations of learning models in the context of PjBL. Figure 7. Integration of the learning model in the application of pjBL in biology education as follows:

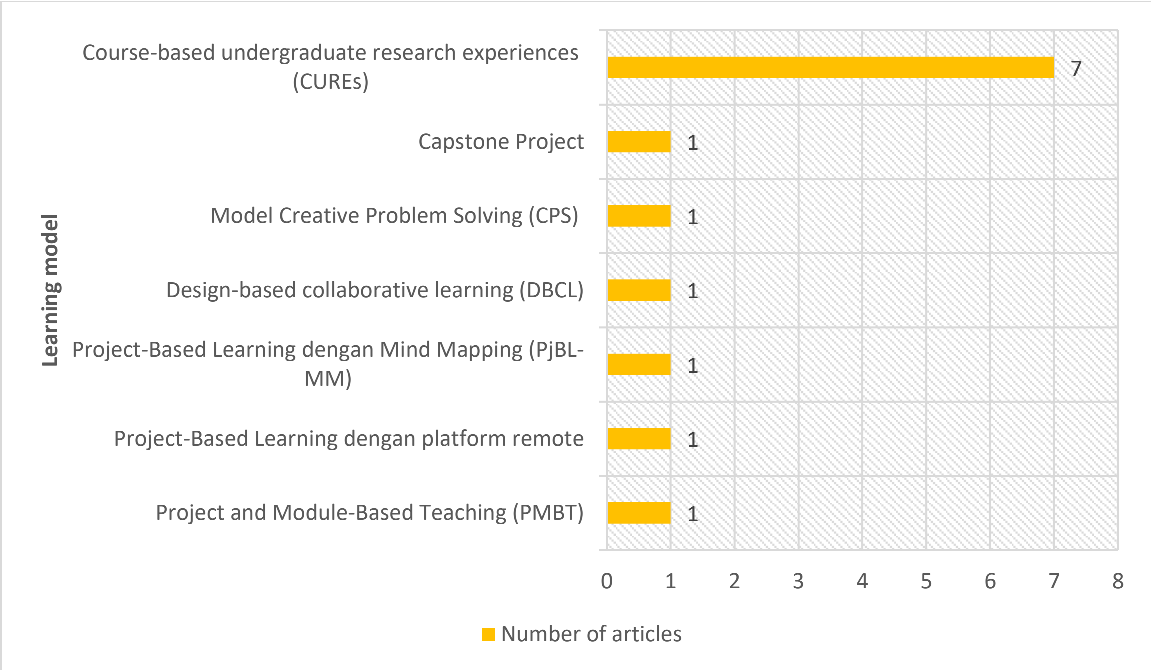

Figure 7. Integration of Learning Models in the Application of PjBL in Biology Education

Based on the graph given, it appears that in the context of PjBL in biology education, there are various learning models that have been integrated. The most widely adopted model is 'Course-based undergraduate research experiences (CUREs),' with a total of seven applications. CUREs can be an effective method in project-based learning to improve specific outcomes for students in terms of self-perception and practical involvement in science (Martin et al., 2021). This suggests that course-based research experience at the undergraduate level is very popular and may be considered effective in implementing PjBL.

Capstone Project, Creative Problem Solving Model (CPS), and Design-Based Collaborative Learning (DBCL) are each integrated once. This may indicate that these three models are considered to have their own uniqueness that can support PjBL in certain scenarios or are considered essential for certain competencies in biology. Whereas for project-based learning with mind mapping (PjBL-MM), project-based learning with remote platforms, and project- and module-based teaching (PMBT), they are all integrated once. The presence of technology in PjBL, such as the use of remote platforms, indicates adaptation to the needs of distance education or hybrid learning.

Overall, this graph depicts the diversity in the integration of learning models in PjBL in the field of biology, which shows the exploration of various methods to enhance student learning experiences and meet various learning goals. This diversity also marks a flexible and responsive approach to the needs of contemporary education, in which lecturers and educators are actively looking for the best ways to integrate research, problem-solving, and collaborative work into the biology curriculum.

Data from this systematic literature review explores how different learning methods are integrated into the PjBL model. From the data presented, there are some key findings that highlight the frequency and type of activity applied in the PJBL. Figure 8.

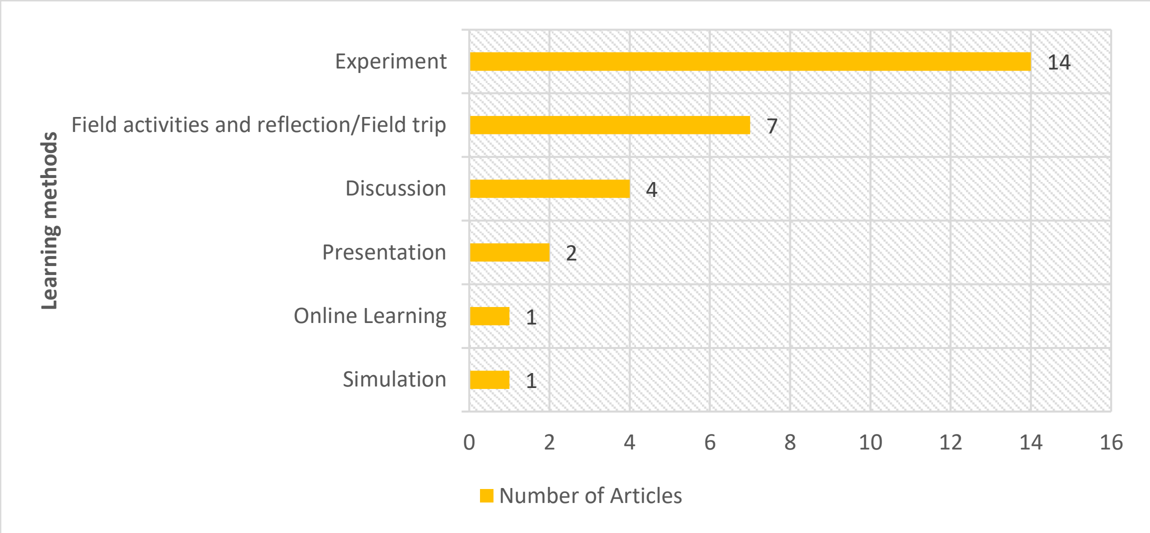

Figure 8. Integration of Learning Methods in the Application of PjBL in Biology Education

Laboratory experimentation is the most frequently integrated learning method in PjBL, with 14 articles. It shows that practical and hands-on activities are still at the heart of many of the pjBL programs; students are actively engaged in the exploration of scientific concepts and practical applications through real experiments in the laboratory (Miller & Krajcik, 2019). These activities enable students to gain in-depth practical experience of scientific and technical principles. The six articles include field activities and reflections that emphasize the significance of experiential learning beyond the classroom. Research on science education shows that teachers play an important role in the planning, implementation, and reflection of field activities, which often determine the impact that such activities will have on students.. Therefore, empowering teachers and developing their ability to design and manage field activities successfully is essential to enabling students to develop an interest in science that may lead to improved learning or better science literacy (Behrendt & Franklin, 2014) Field activities, often in the form of field trips, enrich the learning experience by allowing students to explore concepts in real-world contexts, while the accompanying reflection allows them to reflect and deepen their understanding of the experience.

Simulation, mentioned in one article, may be recognized as an effective tool in providing learning experiences similar to real situations without the practical limitations or risks that may be involved in real experiments or field activities. The discussion, which was integrated into two articles, highlighted the importance of dialogue and the exchange of ideas among students as part of the learning process. Students can consider a variety of perspectives, develop critical thinking skills, and deepen their understanding of the subject being studied. The presentation, also recorded in two articles, indicates that communication and knowledge sharing are important elements of PjBL. The presentation helps students not only in sharpening their communication skills but also in summarizing and communicating the learning outcomes to the audience.

The data overall suggests that PjBL activates various cognitive and practical aspects of student learning through a holistic approach that combines practical experiments, hands-on experiences, simulation-based learning, and interactive methods such as discussions and presentations. The integration of these methods underlines an effort to create a rich and dynamic learning experience that stimulates all dimensions of student learning.

5. Competence Measured in the Application of PjBL in Biology Education

From the systematic literature review data related to the implementation of PjBL, we can draw some interesting findings about the most measured ability classification based on Figure 9.

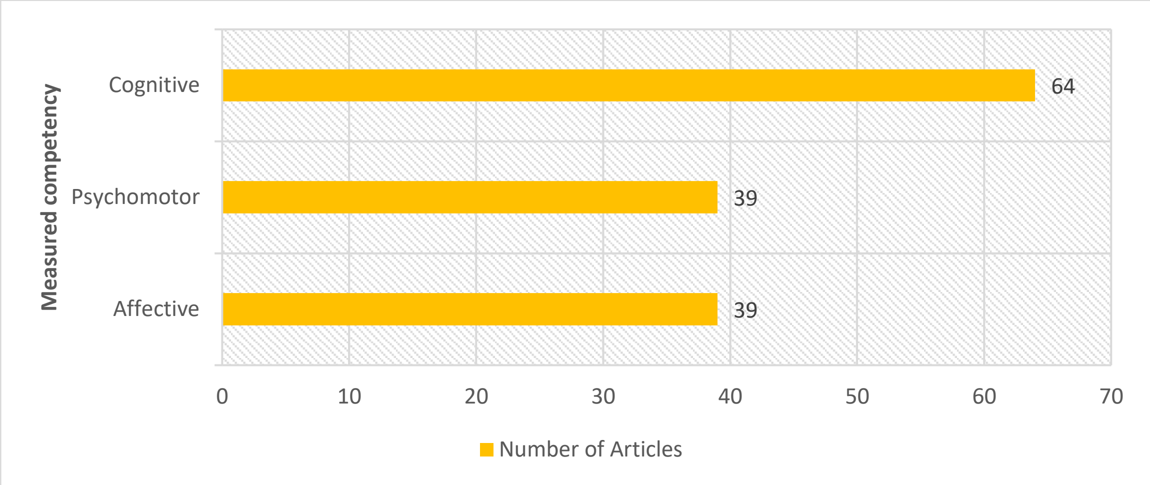

Figure 9. Competence Measured in the Application of PjBL in Biology Education

Cognitive abilities stand out as a major focus, with as many as 64 studies measuring them. It affirms the dominance of intellectual aspects in PjBL, showing that contemporary education highly values the development of student thinking, problem-solving, and conceptual understanding (Afamasaga-Fuata', 2008). The strong focus on cognitive indicates that PjBL is often used to improve intellectual abilities such as analysis, synthesis, and evaluation.

Meanwhile, affective and psychomotor abilities, respectively, were recorded in 39 studies. Both domains indicate that the PjBL approach not only concentrates on the intellectual aspect but also on the development of emotions, values, attitudes (affective), as well as manual or physical skills. (psikomotor). The similarity of the number of studies in these two categories shows an equal recognition of the importance of both aspects in holistic education.

Overall, these findings emphasize that PjBL effectively develops students' abilities comprehensively, with a special focus on cognitive abilities. However, the importance of the affective and psychomotor aspects is also recognized, reflecting the need for a balanced education that not only enriches the intellect of students but also nurtures emotional well-being and physical skills.

D. CONCLUSIONS

The general category 'Biology' dominates the wide application of PjBL in various subdisciplines of biology. Users often use PjBL without specifying a specific sub-discipline, covering various aspects of education and biological development. PjBL is considered effective in improving conceptual understanding and the development of research skills through the use of innovative methods and technology integration. Colleges more often adopt PjBL than high schools. This may reflect greater curricular freedom and opportunities for deeper exploration at the college level. However, its use in high school shows the potential for growth and integration of PjBL at all levels of education. The study of PjBL uses a variety of research methods, with the most common quantitative approaches followed by qualitative and mixed methods. It shows the need to measure outcomes empirically while understanding the learning experience in depth. The integration of various learning approaches into PjBL, including CUREs and

STEM, demonstrates the importance of interdisciplinary and project-based research approaches in biology education. PjBL highly focuses on developing cognitive abilities while also recognizing the importance of affective and psychomotor abilities. This reflects that PjBL is considered effective in developing students' abilities in a comprehensive manner. Overall, PjBL is considered an effective educational strategy that allows students to engage in in-depth and applied learning. This approach emphasizes practical experience, disciplinary integration, and skills development relevant to the 21st century. PjBL offers the opportunity for students to apply theory to real practice and develop essential skills such as critical thinking, teamwork, and communication.

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