International Conference on Education and Innovation
June 2024, pp. 15-24
DOI: xxxx-xxxx

Implementation of Project-Based Learning in 21st Century Learning in Science Learning: A Systematic Literature Review

Arista Ratih[1,2], Festiyed[2], Fitri Arsih[3]

[1] Faculty of Teacher Training and Education, Merangin University, Jambi, Indonesia; aristaratih92@gmail.com
[2] Faculty of Mathematics and Natural Sciences, Padang State University, Padang, Indonesia; festiyed@fmipa.ac.id
[3] Faculty of Mathematics and Natural Sciences, Padang State University, Padang, Indonesia; fitribio@fmipa.ac.id

Abstract: The project-based learning model has received considerable attention in educational research due to its potential to enhance student engagement in 21st century learning. This systematic literature review aims to implement the project-based learning model in 21st century learning. The review synthesizes relevant journal findings published between 2019 and 2024. The databases used were from eric, publish or perish, and google scholar. The journals used are reputable journals indexed by Scopus Q1, Q2, Q3, Q4, Sinta 1 and Sinta 2, 23 articles were obtained that match the theme of project-based learning models in 21st century learning. Descriptive analysis shows that the project-based learning model can develop students' skills in science learning. Through practical projects, students are encouraged to prepare important questions related to a topic of material to be studied, develop a project plan, make a schedule, monitor the implementation of project-based learning, test and provide an assessment of the project created. The review also highlights the positive impact of project-based learning on learning outcomes, student motivation and engagement, and its potential to minimize the achievement gap among learners in science subjects (biology, chemistry and physics). In conclusion, this systematic literature review can build critical thinking skills, creativity skills, communication skills, as well as collaboration skills in its integration with project-based learning in science learning.

Keywords: Project based learning; 21st century learning; Science education

1. INTRODUCTION

The twenty-first century was marked by profound paradigm upheavals on a worldwide scale. This had an impact on how people are perceived and arranged, as well as how they live, work, and interact with society. The globalization of the economic economy, political connections, information, communication, and technology are at the center of significant changes in society. These changes have significant effects on the teaching profession.(Milliken, 2004). Partnership in three broad categories of cognitive skills include communication; thinking and problem solving; and interpersonal and self-direction..(Partnership for 21st Century Skills, 2015).

The scientific community is becoming more and more integrated, which is one of the most notable features of the twenty-first century and is accelerating the synergy between them. It has been demonstrated that the "space and time" component has shrunk and combined in the context of information and communication technology use in education, and that this has been a decisive role in the success and speed of humanity's mastery of science (National Education Standards Agency, 2010). Through the creation of a society made up of quality human resources—that is, people who are self-sufficient, willing, and able to realize their nation's ideals—national education in the twenty-first century seeks to realize the nation's ideals, namely the prosperous and happy Indonesian people who hold an equal and respectable position with other nations in the global community(National Education Standards Agency, 2010).

Creative thinking, divergent thinking, critical thinking, teamwork (particularly in diverse groups), autonomy, developed cognitive and interpersonal skills, social and civic competence, responsible citizenship both nationally and internationally, awareness of interdependence, acceptance and understanding of diversity, recognition and development of personal attributes, interactive tool use, math and science competence, competence, sense of initiative and entrepreneurship, accountability, leadership, cultural awareness and expression, physical well-being are just a few of the professional skills and attributes that are included in 21st century skills (Chalkiadaki, 2018).

The integration of 21st century skills requires important changes in curriculum and school culture. It requires an interdisciplinary vision that goes beyond the divisions between subject domains. To achieve this, new teaching methods as well as stronger collaboration and knowledge sharing structures need to be developed in schools.(Voogt & Roblin, 2010). Learning and innovation skills are increasingly recognized as the skills that separate students who are prepared for the increasingly complex life and work environments of the 21st century, and those who are not. A focus on creativity, critical thinking, communication and collaboration is essential to prepare students for the future.(Partnership for 21st Century Skills, 2015).

Critical-Thinking and Problem-Solving Skills - able to think critically, laterally, and systemically, especially in the context of problem-solving; b. Communication and Collaboration Skills - able to communicate and

collaborate effectively with various parties; c. Critical-Thinking and Problem-Solving Skills - able to think critically, laterally, and systemically, especially in the context of problem-solving; d. Creativity and Innovation Skills - able to develop his/her creativity to produce various breakthroughs; e. Creativity and Innovation Skills - able to develop his/her creativity to produce various breakthroughs; e. Creativity and Innovation Skills - able to develop his/her creativity to produce various breakthroughs. e. Creativity and Innovation Skills: the capacity to harness creativity to generate novel ideas and new breakthroughs; f. Communication and Collaboration Skills: the ability to interact and work together with a variety of people in an efficient manner; f. The literacy of information and communication technologies (ICT) (Badan Standar Nasional Pendidikan, 2010).

Essential 21st-century learning skills include living skills, learning skills, innovation skills, and information and technology usage abilities. To create competent and superior human resources for the period of society 5.0 and industrial revolution 4.0, science education is crucial. Project-based learning (PjBL) has been identified as an efficient approach to enhancing these diverse proficiencies in this instance. People need to know more than just the basics in order to meet the demands of the twenty-first century. They must be able to apply their knowledge and abilities, which includes critical thinking, knowledge application in novel contexts, information analysis, comprehension of novel concepts, communication, teamwork, problem-solving, and decision-making.(Sahin, 2009).

The difficulties facing Indonesia's educational system suggest that the government cannot implement education reform on its own. Public involvement, higher education institutions, and community scholars working together will positively impact how the country's educational system develops.(Sukmayadi & Yahya, 2020). Thomas adopted five criteria to define PBL: 1) "projects are central, not peripheral to the curriculum"; 2) "projects are focused on questions or problems that 'push' students to discover (and wrestle with) key concepts and principles of the discipline"; 3) "projects engage students in constructive inquiry"; 4) "projects are student-driven to a significant degree"; and 5) "projects are realistic, not school-like". Collaboration, in fact, should also be included as the sixth criterion of Project-Based Learning (Mergendoller & Thomas, 2000).

Project-Based Learning (PjBL) is a student-centered learning method where students learn through active engagement in projects relevant to real life. This method has been shown to improve student learning outcomes by integrating theory with practice as well as improving problem-solving, collaboration, and critical and creative thinking skills. Project Based Learning is a learner-oriented learning model involving project work that aims to improve learners' ability to solve problems by acquiring skills involving project work.(Ningsih et al., 2023) Constructivism serves as the foundation for the development of project-based learning. Constructivism creates an environment in the classroom where students must build their own knowledge. With project-based learning, students are given the autonomy to organize their own lessons, work together on projects, and create final products that they may display to others.(Murniati, 2021). Project-based learning is a highly effective method that allows students to express opinions about their areas of interest, ask questions, estimate, develop theories, and use a variety of tools. This approach also allows students to use the skills they are learning in a real-world context. It also allows students to use their skills to solve problems and answer questions in creative ways, both inside and outside the classroom. The project-based learning steps consist of: (1) formulating expected learning outcomes, (2) understanding concept of teaching materials, (3) skills training, (4) designing project themes, (5) making project proposals, (6) carrying out project tasks and (7) presentation of project reports in the form of project reports.(Jalinus et al., 2017)

Project-based education (PjBL) has many benefits for science education. This method allows students to be more actively involved in the learning process and improves their conceptual understanding of science materials and critical and creative thinking skills (Krajcik, 2015). (Krajcik, 2015). In addition, PjBL allows students to use their knowledge to complete projects, which leads to deeper and more meaningful learning. Due to PjBL, students often work together to complete projects. This improves their social and communication skills, which are essential for employment (Holubova, 2008). (Holubova, 2008) In addition, PjBL gives students the opportunity to see how the lessons they are learning have a direct connection to everyday life and the real world, increasing their desire to learn and their interest in science. Project-based learning has great potential to enhance science learning in the 21st century. PjBL can help students prepare for future difficulties and opportunities by integrating theory with practice. For successful implementation, many people have to help and commit to a paradigm shift in education. The purpose of writing this article is to describe how the implication of project-based learning in 21st century learning in science learning through literature review.

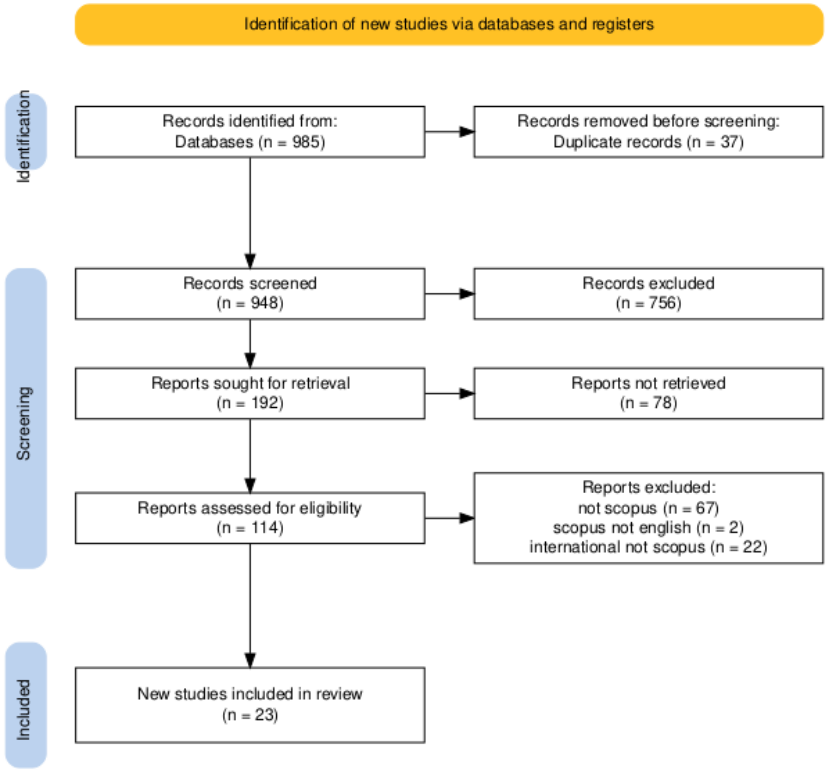
In order to make this article review more focused and directed, the author makes the following research questions:

1. What types of research have implemented project-based learning in 21st century learning in science learning?
2. What countries have implemented project-based learning in 21st century learning in science?
3. What are the research trends that have implemented project-based learning in 21st century learning in science learning?

2. METHODS

The method used in reviewing this article is a systematic literature review with stages adapted from Kitchenham & Charters (2007), namely planning, implementation, and reporting. These three stages are general stages in a series of activities to obtain suitable research subjects. The research subjects consisted of articles published between 2019 and 2024 that examined the integration of ethnoscience in science learning. Data collection techniques review a number of selected articles that meet the criteria. The article selection process used PRISMA.

Because of its methodical stages in the evaluation process, PRISMA was selected. Four steps make up this systematic review, according to (Moher et al., 2009): identification, screening, eligibility, and inclusion. Figure 1 shows the PRISMA systematic review procedure used in this investigation.



During the literature search, articles related to these keywords were found. After checking the suitability of the articles based on the publication year of at least 2019, the number of articles obtained was 985 articles. From these articles, selection was made based on certain criteria, resulting in 23 articles. The criteria used by the researchers included articles published in reputable international journals indexed by Scopus, Sinta 1 articles, Sinta 2 articles, published between 2019 and 2024. The theme of the article is about the implications of project-based learning on 21st century learning in science education. Below are the criteria that must be followed in taking articles:

1. Inclusion Criteria
   a. Searchable articles published in 2019-2024
   b. Articles in Scopus indexed international journals (Q1, Q2, Q3, Q4), sinta 1, and sinta 2
   c. Research topic on the implications of project-based learning on 21st century learning in science education
2. Exclusion Criteria
   a. Literature from international journals but not scopus

b. Articles not in English
c. Articles that are not open access
d. Sinta article 3 and above and not accredited
e. Articles that are not relevant to the theme

3. FINDINGS AND DISCUSSION

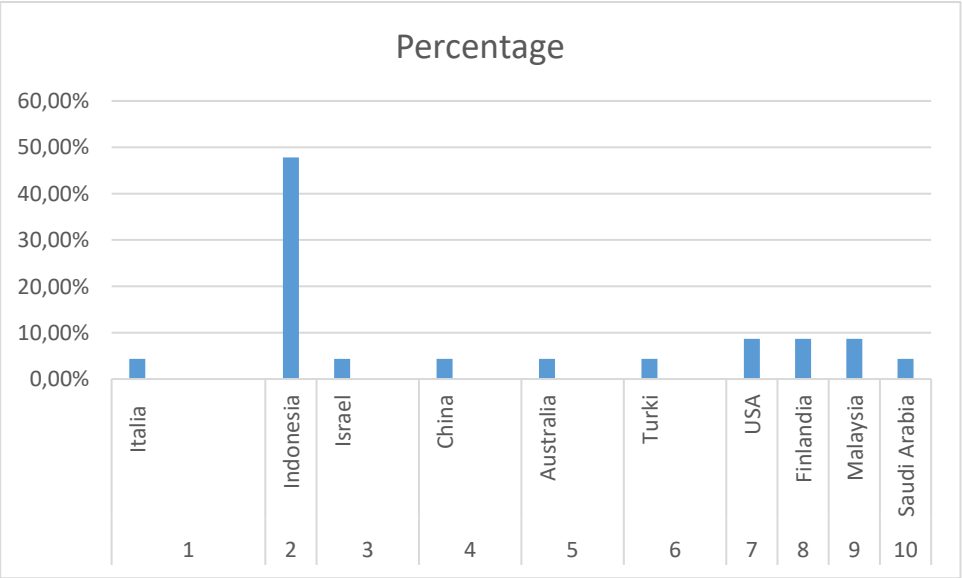
a. Types of Research that have implemented project-based learning in 21st century learning in science learning

No.	Type of research	Percentage
1	Qualitative research	17,39 %
2	Experimental research	43,48 %
3	Mixed methods	8,70%
4	Descriptive Research	13,04 %
5	R and D	8,70 %
6	Case Study	4,35 %
7	Survey	4,35%

The results of the percentage analysis of research types show that research with experimental research dominates with 43.48%, indicating that most of the studies listed in this table use experimental methods to test hypotheses or obtain empirical data. Qualitative research ranks second with 17.39%, indicating that this method is used to gain a deeper understanding of the phenomenon discussed.

Developmental research and mixed methods accounted for 8.70% each, indicating that this research also concentrates on the creation of new methodologies or technologies as well as the use of a combination of qualitative and quantitative methods to obtain more comprehensive results. Although the percentage is lower, the other methods, descriptive 13.04%, comparative case study, and survey, each have a percentage of 4.35%. However, the existence of these different types of research indicates the variety of methodologies used in the listed studies. In empirically testing hypotheses and obtaining quantitative data that can be measured, experimental methods are more common. However, qualitative methods remain important for in-depth exploration and contextual understanding that cannot be achieved by quantitative methods alone. The research results are enriched by the combination of these methods, and the problem under study is viewed from a broader perspective.

b. Research countries that have implemented project-based learning in 21st century learning in science learning



Indonesia dominates at almost 50% according to the data in the table, which shows that half of the researchers in the journal index are from Indonesia. While the majority of research contributions come from one country, namely Indonesia, other contributing countries are the United States, Finland and Malaysia, each with 9%, and Italy, Israel, China, Turkey, and Saudi Arabia, each with 4%. This shows the geographical variation in contributions. The dominance of this journal in Indonesia may indicate a stronger research focus on relevant topics in Indonesia or the activeness of researchers in the country in journal publications. In addition, the author did not only take scopus indexed journals but also sinta 1 and sinta 2 which automatically the country of the researcher comes from Indonesia

c. Research on implementing project-based learning in 21st century science learning

No.	Author	Research Results
1	(Domenici, 2022)	The main findings of the study, confirmed the value of non-formal learning environments and the STEAM Project-Based Learning approach in training prospective chemistry teachers. The conclusion suggests that the integration of creative and multidisciplinary activities in teacher education programs can significantly enhance the learning experience and better prepare teachers for their future roles.
2	(Shiyamsyah et al., 2024)	The outcomes demonstrated the validity and applicability of the project-based learning module on plant growth and development material for preparing community members for the bioentrepreneurship of era 5.0. By combining plant growth and development materials with microgreens growing project activities in the project-based learning module, students' bioentrepreneurship skills can be strengthened.
3	(Hugerat et al., 2020)	Students' enthusiasm to learn science was much enhanced by the implementation of project-based science learning didactic games in the classroom, which also had a favorable impact on all aspects of the learning environment as judged by the students. The classroom environment improved more in didactic game-using classes than in non-didactic game-using classes..
4	(Tian et al., 2023)	Students' conceptual growth and key learning competencies—such as problem-solving, information integration, communication and teamwork, and self-learning independence—are effectively enhanced by microproject-based learning. The results of this study will influence pedagogical advancements in the teaching and learning of chemistry.
5	(Muzana et al., 2021)	Problem solving and ICT literacy are very different from one another. The application of the E-STEM project-based learning model and issue solving in science learning has a substantial impact on enhancing ICT literacy and problem solving, according to the differences between the two learning approaches.
6	(Hart, 2019)	The results showed that there was a significant difference between the way students saw student skill improvement and the way they measured skill improvement. Projects with a narrow scope of disciplines more often resulted in improved disciplinary skills, while projects with a broad scope of disciplines more often resulted in improved communication and teamwork. In addition, projects with a broad scope of disciplines and requiring integration of disciplinary skills were significantly associated with increased perceived interdisciplinary effectiveness. According to this study, although interdisciplinary PjBL has great potential to improve important employability skills for students, a more structured and objective assessment approach is needed to ensure that these skill improvements actually occur and are not just perceptions.
7	(Sudarmin et al., 2023)	The project-based learning model of secondary metabolite chemistry in essential oils and terpenes courses and learning tools with the EthnoSTEM approach is feasible and effective for improving student conservation and entrepreneurial character with moderate and high criteria. With moderate and high criteria based on N-gain scores. Entrepreneurial characters, which include perseverance, discipline, and creativity, have been developed so that students can produce products and are suitable for sale.
8	(Hindun et al., 2024)	The results showed that the average of science literacy and collaboration in PjBL learning was higher than conventional learning. Based on the results of the analysis, it can be concluded that the implementation of PjBL effectively affects students' science literacy and collaboration skills.

9	(Kilic & Ozel, 2022)	Students and teachers in Turkey about the implementation of project-based learning (PBL) in science subjects are discussed in this study. Most teachers believe that PBL is difficult to implement due to large class sizes, dense curriculum and short lesson duration. They suggest reducing class sizes and curriculum content and increasing lesson duration. With parental help at home, students feel free to choose project topics and are confident in preparing them. Projects are graded on effort, usefulness, originality and aesthetics by the teacher. Although PBL is considered useful, there are many problems in implementing it in schools.
10	(Lukitasari et al., 2021)	Project-based learning (PBL) can develop students' metacognitive abilities developed through e-portfolio-based documents that students do while fulfilling all project tasks.
11	(Irdalisa; et al., 2024)	The implementation of project-based learning combined with the analysis of STEAM-based student worksheets using20 endid ecoprint resulted in substantial improvements in students' learning motivation and creativity.
12	(Miller et al., 2021)	This study found that Project-Based Learning (PBL) can be effectively adapted in virtual teaching, despite facing various challenges, such as technical limitations and student supervision. Two elementary school teachers successfully maintained the four key features of PBL (driving questions, continuous learning, collaboration, and community connections) in virtual teaching, with each teacher prioritizing different features to support equity goals. The results of this study suggest that creative PBL approaches and technological support can overcome some of the challenges of virtual teaching and support student engagement and the achievement of equitable learning goals.
13	(Haatainen & Aksela, 2021)	Project-Based Learning (PBL) in integrated science education has many advantages, but also faces some challenges. The majority of teachers consider that PBL improves students' 21st century skills, such as problem solving, collaboration and critical thinking. PBL is also considered effective in increasing student motivation and engagement, and encouraging collaboration between students, teachers and communities. However, the main challenges in implementing PBL are time management, time-consuming planning, limited resources, as well as difficulties in facilitating projects and maintaining student motivation. This study concludes that although teachers have a general understanding of the advantages of PBL, they still need support in the aspects of formative assessment and the critique and revision phase to achieve more effective PBL implementation.
14	(Baudin et al., 2022)	This research shows that the use of internet-connected (IoT) microscopes in remote project-based learning (PBL) significantly increases student interest and engagement in science, particularly in underserved Latinx communities. Through this program, students from high schools in California and universities in Bolivia were able to conduct real-time biology experiments using Picroscope and Streamscope devices, which enable remote observation and data analysis. The results showed that remote PBL was as effective as face-to-face PBL in improving students' understanding of the scientific method and increasing their interest in pursuing careers in STEM fields. Students reported an increased STEM identity and felt more motivated to study science after participating in the program. In addition, this study highlights the flexibility and scalability of this approach, which can be adapted for a variety of20 endi contexts and used simultaneously in different geographical locations, opening up new opportunities for the democratization of20 endi STEM education worldwide.
15	(Sulaiman et al., 2023)	This study shows that the STEM-integrated Project-based physics module is effective in increasing students' personal interest, sense-making, and effort in learning physics. The implementation of this module can be an effective approach to increase students' engagement and motivation in learning physics, especially in the context of20 secondary education in Malaysia and South Korea. This study also provides recommendations for the development of similar modules in the future and the importance of support from various stakeholders in the implementation of20 STEM education.
16	(Hanif et al., 2019)	The application of STEM project-based learning is effective in enhancing students' creativity on the topic of light and20 ptic at the Junior High School level. STEM project-based learning can be used as an effective teaching strategy to enhance 21st century skills and prepare students for future technological challenges.

17	(Almulla, 2020)	21This study found that the Project-Based Learning (PBL) approach significantly increased student engagement in learning, with results showing that PBL had a positive and significant relationship with collaborative learning (CL), disciplinary subject learning (DSL), inquiry learning (IL), and authentic learning (AL). Through21 endid conducted with 124 teachers, data analyzed using Structural Equation Models (SEM) showed that PBL not only increased student engagement (SEL) but also developed 21st century skills such as collaboration, problem solving, and critical thinking. These findings confirm that the implementation of PBL is effective in creating a more interactive and meaningful learning environment, and therefore, it is highly recommended for use in21 higher education.
18	(Wardani et al., 2020)	PjBL can help student teachers become more adept at creating lesson plans that align with the relevant curriculum, student personalities, and 21st century abilities. The assessment results, which considerably improved from 2.04 to 3.25, support this conclusion. This is likewise predicated on the Wilcoxon test, which yields 0.000 as the Asymp.Sig. (2-tailed) < 0.05 result. This indicates that there is an impact on the abilities of aspiring primary school teachers to write science teaching materials, in the form of a rise in the application of the PjBL model.
19	(Sumarni & Kadarwati, 2020)	ethno-STEM project-based learning shows a significant effect on improving students' critical and creative thinking skills.
20	(Yustina et al., 2020)	Prospective biology teachers' capacity for creative thought is enhanced by blended learning and project-based learning, and BL and Pj-BL are more successful than conventional methods at fostering this capacity when learning biology.
21	(Samsudin et al., 2020)	The results illustrate that STEM PjBL increases students' self-efficacy in solving physics problems. In addition, this study also proposes guidelines for future research.
22	(Latifah et al., 2020)	Applying the PjBL approach results in higher-quality learning outcomes. Therefore, it can be said that the study's findings demonstrated the scenario and application of learning, as evidenced by the average scores of 77.89% for teachers and students, which included the good category; the 82% and 84% scores for teachers and students, respectively, which included the very good category; and the 27% average for students' difficulties in understanding the problem and coming up with solutions.
23	(Juuti et al., 2021)	Student engagement increased significantly from year one to year two, with a 20% increase in situations where students reported high levels of engagement. Although there was little change in the frequency of PBL features reported by students, they felt more engaged in activities such as planning and conducting investigations, analyzing data, working with computers, and working in groups. This study concludes that the TRP approach is effective in improving teacher professional learning and student engagement through the process of co-design, implementation, and joint reflection on the PBL unit.

Research shows that PBL can improve various important skills in the 21st century. For example, (Hindun et al., 2024) found that the use of PBL was more effective than conventional learning methods in improving students' science literacy and collaboration skills. Research by (Tian et al., 2023) also showed that micro PBL also helps students learn independently and solve problems. Hanif et al. (2019) and Wardani et al. (2020) found that STEM-based PBL can improve students' creativity in light and optic subjects in junior high school. They also found that PBL can help prospective teachers create teaching materials that are relevant to modern skills.

In addition, research shows that PBL can be more effective when combined with other methods and technologies. Baudin et al. (2022) found that using internet-connected microscopes (IoT) in remote PBL increased students' interest and engagement in science. Miller et al. (2021) stated that, despite facing a number of technical issues, PBL can be applied successfully in virtual teaching. Studies show that PBL improves academic and character skills as well as entrepreneurial skills. According to Sudarmin et al. (2023), the PBL model of secondary metabolite chemistry in essential oils and terpenes courses successfully improved students' entrepreneurial and conservation traits. In addition, Shiyamsyah et al. (2024) found that PBL teaching modules focusing on plant growth and development materials can be used to teach skills known as bioentrepreneurship in the era of society 5.0.

Hugerat et al. (2020) conducted a study showing that the use of PBL didactic games in science teaching can increase students' desire to learn as well as elements of the learning environment. Irdalisa et al. (2024) found similar results, showing that analyzing STEAM worksheets with PBL can increase students' creativity and desire to learn**.** PBL implementation has some challenges despite its many benefits. According to Kilic and Ozel (2022),

large class sizes, a dense curriculum, and short lesson duration make it difficult for teachers in Turkey to implement PBL. Haatainen & Aksela (2021) also emphasized several issues, including time management, planning that requires a lot of time, a limited amount of resources, and problems in facilitating projects and keeping students motivated**.** To overcome these challenges, several recommendations can be proposed. For example, reducing class size and curriculum content and increasing lesson duration as suggested by Kilic & Ozel (2022). In addition, technological support and creative approaches in virtual PBL as proposed by Miller et al. (2021) can help overcome technical challenges and ensure student engagement.

4. CONCLUSION

Project-based education (PBL) has proven to be an effective teaching method in science education this century. Research from 23 journals shows that PBL significantly improves critical skills such as creativity, critical thinking, collaboration, and science literacy. As shown by the studies of Miller et al. (2021) and Baudin et al. (2022), PBL is effective in face-to-face learning and can be applied in virtual learning with technology support. PBL is more effective in building conservation character and entrepreneurial skills when combined with other methods such as STEAM and ethno-STEM.

Project-based learning also has challenges including time management, limited resources, and a dense curriculum. To address these issues, studies by Kilic & Ozel (2022) and Haatainen & Aksela (2021) suggest that adjustments to class size and lesson duration are needed. To increase the effectiveness of PBL, it is recommended to decrease class size, simplify the curriculum, and increase lesson duration. Overall, project-based learning is a learning method that can make students' learning experience more profound and meaningful. With proper support and customization, project-based learning can become the dominant teaching method in science education this century and prepare students with the skills they need to succeed in the future.

REFERENCES

Almulla, M. A. (2020). The Effectiveness of the Project-Based Learning (PBL) Approach as a Way to Engage Students in Learning. *SAGE Open*, *10*(3). https://doi.org/10.1177/2158244020938702

Badan Standar Nasional Pendidikan. (2010). Paradigma Pendidikan Nasional Abad XXI. *Paradigma Pendidikan Nasional Abad XXI*, 1–59.

Baudin, P. V., Sacksteder, R. E., Worthington, A. K., Voitiuk, K., Ly, V. T., Hoffman, R. N., Elliott, M. A. T., Parks, D. F., Ward, R., Torres-Montoya, S., Amend, F., Montellano Duran, N., Vargas, P. A., Martinez, G., Ramirez, S. M., Alvarado-Arnez, L. E., Ehrlich, D., Rosen, Y. M., Breevoort, A., … Mostajo-Radji, M. A. (2022). Cloud-controlled microscopy enables remote project-based biology education in underserved Latinx communities. *Heliyon*, *8*(11), e11596. https://doi.org/10.1016/j.heliyon.2022.e11596

Chalkiadaki, A. (2018). A systematic literature review of 21st century skills and competencies in primary education. *International Journal of Instruction*, *11*(3), 1–16. https://doi.org/10.12973/iji.2018.1131a

Domenici, V. (2022). STEAM Project-Based Learning Activities at the Science Museum as an Effective Training for Future Chemistry Teachers. *Education Sciences*, *12*(1). https://doi.org/10.3390/educsci12010030

Haatainen, O., & Aksela, M. (2021). Project-based learning in integrated science education: Active teachers' perceptions and practices. *Lumat*, *9*(1), 149–173. https://doi.org/10.31129/LUMAT.9.1.1392

Hanif, S., Wijaya, A. F. C., & Winarno, N. (2019). Enhancing Students' Creativity through STEM Project-Based Learning. *Journal of Science Learning*, *2*(2), 50. https://doi.org/10.17509/jsl.v2i2.13271

Hart, J. (2019). Interdisciplinary project-based learning as a means of developing employability skills in undergraduate science degree programs. *Journal of Teaching and Learning for Graduate Employability*, *10*(2), 50–66. https://doi.org/10.21153/jtlge2019vol10no2art827

Hindun, I., Nurwidodo, N., Wahyuni, S., & Fauziah, N. (2024). Effectiveness of project-based learning in improving science literacy and collaborative skills of Muhammadiyah middle school students. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *10*(1), 58–69. https://doi.org/10.22219/jpbi.v10i1.31628

Holubova, R. (2008). Effective teaching methods —Project-based. *US-China Education*, *5*(12), 1548–6613. https://files.eric.ed.gov/fulltext/ED504949.pdf

Hugerat, M., Kortam, N., Maroun, N. T., & Basheer, A. (2020). The Educational Effectiveness of Didactical Games in Project-based Science Learning among 5th Grade Students. *Eurasia Journal of Mathematics, Science and Technology Education*, *16*(10), 1–12. https://doi.org/10.29333/ejmste/8490

Irdalisa;, Zulherman;, Elvianasti, M., Widodo;, W. S., & Hanum, E. (2024). International Journal of Educational Methodology Effectiveness of Project-Based Learning on STEAM-Based student ' s worksheet analysis With Ecoprint Technique. *International Journal of Educational Methodology*, *10*(1), 923–935.

Jalinus, N., Nabawi, R. A., & Mardin, A. (2017). *The Seven Steps of Project Based Learning Model to Enhance Productive Competences of Vocational Students*. *102*(Ictvt), 251–256. https://doi.org/10.2991/ictvt-17.2017.43

Juuti, K., Lavonen, J., Salonen, V., Salmela-Aro, K., Schneider, B., & Krajcik, J. (2021). A Teacher–Researcher Partnership for Professional Learning: Co-Designing Project-Based Learning Units to Increase Student Engagement in Science Classes. *Journal of Science Teacher Education*, *32*(6), 625–641. https://doi.org/10.1080/1046560X.2021.1872207

Kilic, I., & Ozel, M. (2022). Teachers' and students' views about the applicability of the project-based learning approach in science courses in Turkey. *South African Journal of Education*, *42*(3), 1–9. https://doi.org/10.15700/saje.v42n3a2103

Krajcik, J. (2015). Projected-Based Science. *The Science Teacher*, *82*(1).

Latifah, N., Fauzia, U., & Kelana, J. B. (2020). Natural Science Problem Solving in Elementary School Students Using the Project Based Learning (PjBL) Model. *Jurnal Ilmiah Sekolah Dasar*, *4*(4), 596–603.

Lukitasari, M., Hasan, R., Sukri, A., & Handhika, J. (2021). Developing student's metacognitive ability in science through project-based learning with e-portfolio. *International Journal of Evaluation and Research in Education*, *10*(3), 948–955. https://doi.org/10.11591/IJERE.V10I3.21370

Mergendoller, J. R., & Thomas, J. W. (2000). Managing project based learning: Principles from the field. *Annual Meeting of the American Educational Research Association*, 1–51. http://www.bie.org/images/uploads/general/f6d0b4a5d9e37c0e0317acb7942d27b0.pdf

Miller, E. C., Reigh, E., Berland, L., & Krajcik, J. (2021). Supporting Equity in Virtual Science Instruction Through Project-Based Learning: Opportunities and Challenges in the Era of COVID-19. *Journal of Science Teacher Education*, *32*(6), 642–663. https://doi.org/10.1080/1046560X.2021.1873549

Milliken, J. (2004). Thematic reflections on higher education. *Higher Education in Europe*, *29*(1), 9–18. https://doi.org/10.1080/03797720410001673265

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., Antes, G., Atkins, D., Barbour, V., Barrowman, N., Berlin, J. A., Clark, J., Clarke, M., Cook, D., D'Amico, R., Deeks, J. J., Devereaux, P. J., Dickersin, K., Egger, M., Ernst, E., Gøtzsche, P. C., … Tugwell, P. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine*, *6*(7). https://doi.org/10.1371/journal.pmed.1000097

Murniati, E. (2021). Penerapan Metode Project Based Learning Dalam Pemmbelajaran. *Journal of Education*, *3*(1), 1–18.

Muzana, S. R., Jumadi, Wilujeng, I., Yanto, B. E., & Mustamin, A. A. (2021). E-STEM project-based learning in teaching science to increase ICT literacy and problem solving. *International Journal of Evaluation and Research in Education*, *10*(4), 1386–1394. https://doi.org/10.11591/IJERE.V10I4.21942

Ningsih, P. O., Alkhasanah, N., Isnaini, Y. F., Maulana, I., Hidayati, Y. M., & Desstya, A. (2023). Penerapan Model Project Based Learning Dengan Pendekatan Tpack Pada Pembelajaran Ipa. *Jurnal Ilmiah Pendidikan Citra Bakti*, *10*(4), 707–721. https://doi.org/10.38048/jipcb.v10i4.1904

Partnership for 21 st Century Skills. (2015). Partnership for 21St Century Skills-Core Content Integration. *Ohio Department of Education*, 1. www.P21.org.

Sahin, M. C. (2009). Instructional design principles for 21st century learning skills. *Procedia - Social and Behavioral Sciences*, *1*(1), 1464–1468. https://doi.org/10.1016/j.sbspro.2009.01.258

Samsudin, M. A., Jamali, S. M., Zain, A. N. M., & Ebrahim, N. A. (2020). The effect of STEM project based learning on self-efficacy among high-school physics students. *Journal of Turkish Science Education*, *17*(1), 94–108. https://doi.org/10.36681/tused.2020.15

Shiyamsyah, F. S. F., Yuliani, Y., & Rahayu, Y. S. (2024). Validity and practicality of project-based learning teaching modules to train life skills Era Society 5.0 (bioentrepreneurship). *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *10*(1), 96–106. https://doi.org/10.22219/jpbi.v10i1.30141

Sudarmin et al. (2023). CHEMISTRY PROJECT-BASED LEARNING FOR SECONDARY METABOLITE COURSE WITH ETHNO-STEM APPROACH TO IMPROVE STUDENTS' CONSERVATION AND ENTREPRENEURIAL CHARACTER IN THE 21ST CENTURY. *Journal of Technology and Science Education*, *13*(1), 393–409.

Sukmayadi, V., & Yahya, A. H. (2020). Indonesian education landscape and the 21st century challenges. *Journal of Social Studies Education Research*, *11*(4), 219–234.

Sulaiman, F., Rosales, J. J., & Kyung, L. J. (2023). the Effectiveness of the Integrated Stem-Pbl Physics Module on Students' Interest, Sensemaking and Effort. *Journal of Baltic Science Education*, *22*(1), 113–129. https://doi.org/10.33225/jbse/23.22.113

Sumarni, W., & Kadarwati, S. (2020). Ethno-stem project-based learning: Its impact to critical and creative thinking skills. *Jurnal Pendidikan IPA Indonesia*, *9*(1), 11–21. https://doi.org/10.15294/jpii.v9i1.21754

Tian, P., Sun, D., Han, R., & Fan, Y. (2023). Integrating Micro Projectbased Learning To Improve Conceptual

Understanding and Crucial Learning Skills in Chemistry. *Journal of Baltic Science Education*, *22*(1), 130–152. https://doi.org/10.33225/jbse/23.22.130

Voogt, J., & Roblin, N. P. (2010). 21 st CENTURY SKILLS DISCUSSION PAPER. *Pacific Policy Research Center in Research & Evaluation (2010)*. http://hdl.voced.edu.au/10707/254371.

Wardani, D. S., Fauzi, M. R., Zafira, R., & Kurniawati, D. (2020). Creating Props: Improving Writing Skills of Teaching Materials of Elementary Teacher Education Students through Project-Based Learning Model. *Mimbar Sekolah Dasar*, *7*(2), 216–234. https://doi.org/10.17509/mimbar-sd.v7i2.26334

Yustina, Syafii, W., & Vebrianto, R. (2020). The effects of blended learning and project-based learning on pre-service biology teachers' creative thinking skills through online learning in the COVID-19 pandemic. *Jurnal Pendidikan IPA Indonesia*, *9*(3), 408–420. https://doi.org/10.15294/jpii.v9i3.24706