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# Innovative Approaches to Physics Education in Merdeka Curriculum: The Impact of STEM-Integrated Project-Based Learning on 21st Century Skills

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***ABSTRACT***
*STEM-integrated project based learning (STEM-PjBL) is an ideal learning model recommended in the Merdeka Curriculum to achieve 21st century education goals, because it involves the principles of critical thinking, communication, collaboration, creativity, character, citizenship, and computational thinking skills. This study aims to explore the development of international and national research publications on the STEM-PjBL indexed by Scopus in the 2020-2024 period using a systematic literature review (SLR) assisted by the VOSViewer program, and to examine its impact on the achievement of 21st century skills. The analysis included 68 articles selected using the Prisma technique. This study proposes the following findings: (1) the implication that is often used is the type of quantitative research with quasi-experimental methods, the research subjects are students or students at the senior high school (SMA) level with a small scale sample size of less than 50 respondents, (2) research is widely used to analyze the achievement of creativity skills but no one has studied the impact of STEM-PjBL on citizenship skills. However, the PjBL-STEM model is proven effective for improving of 21st century skills so that it is suitable for the Merdeka Curriculum outcomes. Future research is expected to use additional bibliographic sources such as Web of Science and Google Scholar.*

## INTRODUCTION

Education in Indonesia is currently still facing various challenges, both national and global. Based on the results of the survey of secondary education systems in the world in 2022 issued by PISA (Program for International Student Assessment), Indonesia is ranked 75th out of 80 other countries with an average of 371 for literacy and 374 for numeracy [1]. This score is still in the category below the international average of 476 for literacy and 472 for numeracy. Based on this, Indonesia is below

the minimum competency in education, especially literacy and numeracy. In fact, there are still disparities in the quality of education in various regions. Many schools in remote areas lack adequate facilities and resources, which results in low quality teaching and learning [2]. The education system in the 21st century needs to prepare a generation that is able to respond to various challenges, both national and global [3] [4] [5]. To overcome these issues, it is crucial to implement targeted educational reforms that focus on improving teaching quality and student engagement.

Learning in the 21st Century aims to create individuals who not only have academic knowledge but also the practical skills needed to meet the challenges and opportunities in the Industrial Revolution 4.0 Era. The key skills for life in the 21st Century are known as the 7C, namely: character, citizenship, critical thinking, computational thinking, creativity, collaboration, and communication [6]. The education system in Indonesia needs to strengthen and develop these competencies so that students are ready to face the Industrial Revolution 4.0 [7]. Thus, the development of 7C skills is essential in responding to the demands and changes brought by the Industrial Revolution 4.0. This can be realized in the STEM approach. The STEM approach is proven to develop of critical 21st-century skills, prepare students for future careers and foster responsible innovative citizens [8]. Ultimately, the synergy between STEM education and the development of 21st-century skills prepares students for future careers.

In an effort to improve the quality of education in Indonesia to produce a generation that has global competitiveness, the government through the Ministry of Education and Culture launched the Merdeka Curriculum program which creates an educational environment that is more dynamic, relevant, and responsive to the needs of students and the demands of the world of work in the era of the Industrial Revolution 4.0. Based on the Decree of the Head of the Education Standards, Curriculum and Assessment Agency of the Ministry of Education, Culture, Research and Technology Number 044/H/KR/2022, the government stipulates the implementation of the Merdeka Curriculum to more than 140 thousand educational units in the 2022/2023 school year. In the basic framework of the independent curriculum, there is a project program to strengthen the profile of Pancasila students using the project-based learning (PjBL) model to observe and think about solutions to problems in the surrounding environment [9] [10] [11]. By integrating the PjBL learning model in the Merdeka Curriculum, education can become more contextual, relevant, and provide in-depth learning experiences for students.

Project-based learning model is an ideal learning model to achieve 21st century education goals, because it involves the principles of critical thinking as well as problem solving, interpersonal communication, information and media literacy, collaboration, leadership and teamwork, innovation and creativity [10][12]. The integration between Project-based learning (PjBL) and STEM (Science, Technology, Engineering, and Mathematics) can create a more contextual, relevant, and immersive learning experience [13]. STEM-integrated project based learning (STEM-PjBL) model has become a rapidly growing research trend at the national and international levels. STEM-PjBL emphasizes the importance of integrating science, technology, engineering and mathematics in education to prepare students for the challenges of the 21st century. Studies in various countries show that this approach can improve students' critical thinking, problem solving and collaboration skills [14] [15] [16] [17] [18]. Physics is closely related to the integrated elements of STEM because physics is the power of innovation and the development of the latest technology [19] [20]. By integrating STEM-PjBL in physics learning in Merdeka Curriculum, education can become more responsive to the demands of the times, producing graduates who not only excel in academic knowledge but also in skills that are highly valued in the 21st Century. Therefore, this study aims to determine the development trend of STEM-PjBL research in physics learning, as well as its impact on the achievement of 21st Century skill, so that it is expected to help the implementation of the STEM-PjBL model in physics learning in the Merdeka Curriculum in Indonesia.

## METHOD

This research is a Systematic Literature Review (SLR) using the content analysis method. SLR is a systematic and structured research method used to identify, evaluate, and synthesize previous studies relevant to a particular research topic [21] [22]. The literature search was conducted using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analysis) method. The PRISMA method consists of 4 stages as shown in Figure 1 [23].

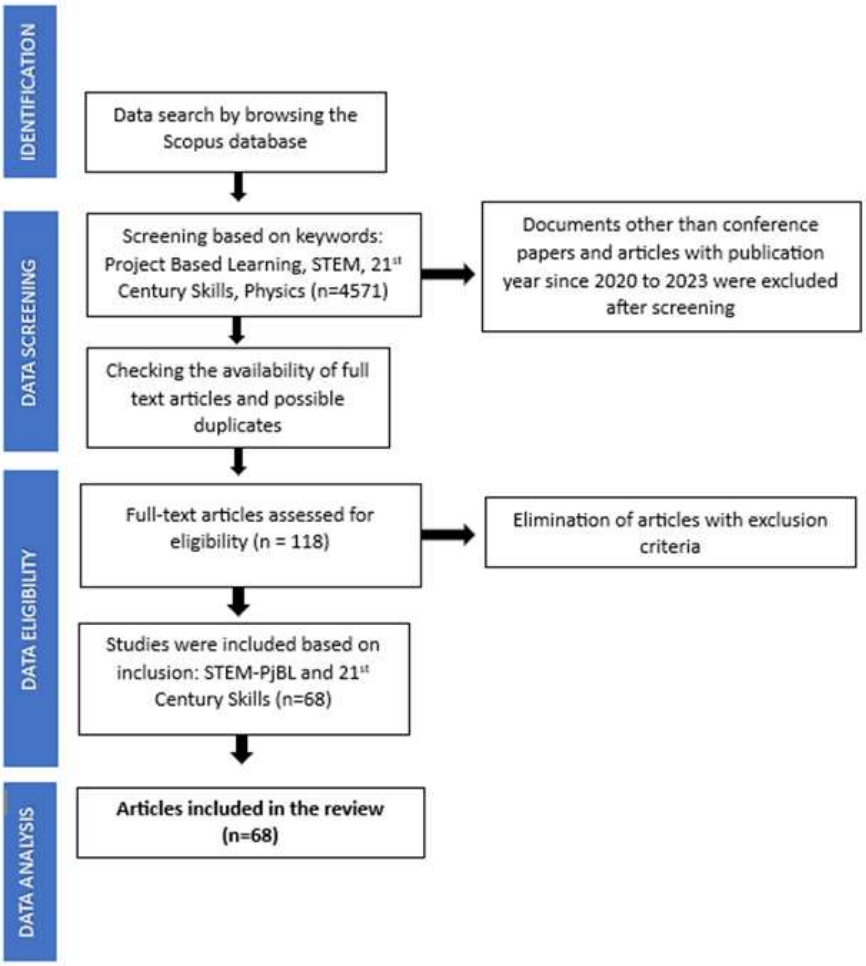


***Fig 1**. PRISMA Flow Diagram*

*Identification*

The Scopus database was searched using the keywords "Project-based learning", "STEM", "21st Century Skills" and "Physics" in the categories of title, abstract and keywords using Publish or Perish 8 software. Scopus was selected due to its reputation as a comprehensive and reliable source of systematic literature review, ensuring high-quality and up-to-date research results. Its extensive coverage of multidisciplinary fields makes it an ideal choice for analyzing trends in STEM-PjBL research in physics learning research. In the initial search, researchers found 4571 documents.

*Data screening*

Data screening is used to screen the data that has been obtained so that the data is consistent with the topic to be discussed. The volume of data that was available and indexed in the Scopus database was screened by the researchers. The selected research data were only open access article and conference paper in publications in last 5 years from 2020 to 2024. At this stage, the researchers were able to obtain 118 completed articles.

*Data eligibilty*
The assessment of the eligibility of the data began with the inclusion and exclusion criteria that had been proposed. The researcher considered the suitability with the research topic discussed. The research focused on efforts to improve 21st century skills through STEM-integrated project-based learning (STEM-PjBL) as a learning model that is in accordance with Merdeka Curriculum. At this stage, the researcher managed to obtain 68 complete articles.

*Data analysis*
The results of the data search will then be reported and analyzed statistically using Microsoft Excel 2019. In addition, the data were exported in Comma Separate Values (CSV) format. Finally, the data were processed using the VOSViewer software version 1.6.19. to visualize the research trend of STEM- integrated project based learning (STEM-PjBL) in physics learning.

## RESULTS AND DISCUSSIONS

*Trend of STEM-PjBL Research in Physics Education*
The learning model is a planning formula that is set as a guide by the educator and will be applied to the learning activity. STEM-integrated project based learning (STEM-PjBL) is an educational program in which students acquire core skills through the design, development, and completion of projects [24] [25]. The implementation of the STEM-PjBL model involves five key phases: the relation phase, research phase, discovery phase, application phase, and communication phase. This allows learners to explore ideas, develop products, and develop further planning capabilities [26]. In addition, the STEM-PjBL model empowers students to take an active role in the learning process, encouraging them to think critically and creatively. This certainly supports the attainment of 21st century skills.

STEM-integrated project based learning (STEM-PjBL) research in physics learning has become the most popular research topic in Indonesia. The highest number of STEM-PjBL research occurred in 2021 as shown in Figure 2. From 2022 to 2024, a slight decline in research output can be observed, possibly due to shifting research priorities toward emerging topics such as digital literacy and artificial intelligence in education. However, the number of publications remained relatively stable in the 2020-2023 with an average number of publications of 14 publications by year. This is consistent with the results of the analysis which Indonesia as the country that has applied the most STEM-PjBL research articles in physics education. Indonesia made up 54.92% of the total number of STEM-PjBL research articles in physics learning for the last five years (2020-2024). This is in line with the efforts of the Indonesian government in improving the quality of education to produce globally competitive graduates.

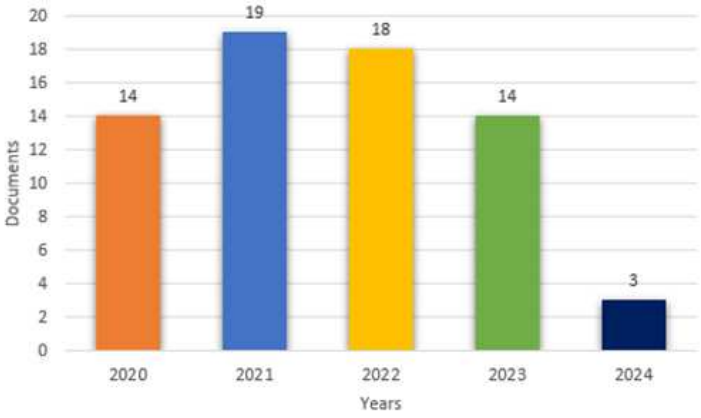


***Fig 2**. Annual Publications of STEM-PjBL Research in Physics Education*

Based on the results of the co-aulthorship analysis, the development of the STEM-integrated project based learning (STEM-PjBL) in physics education is not widespread in the ASEAN region. Only three of the countries in the ASEAN region have published articles by Scopus on this research topic as shown in Figure 3.

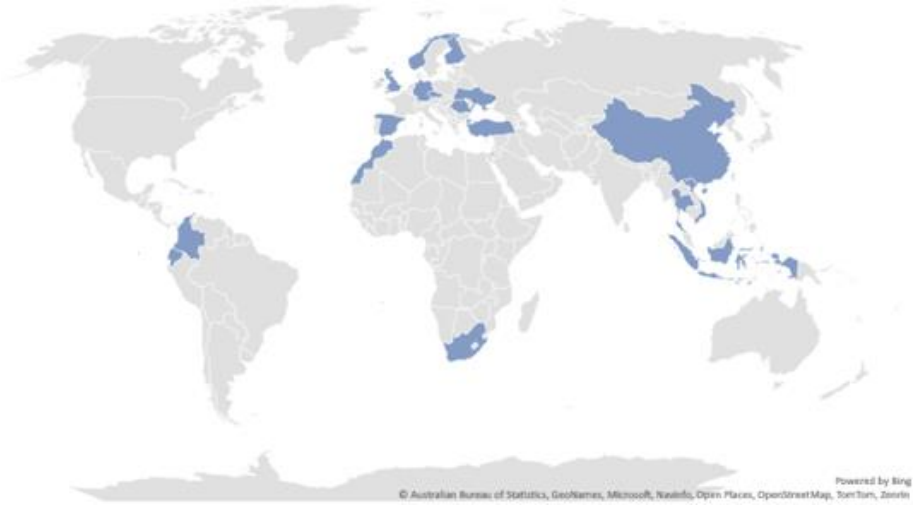

***Fig 3**. Distribution of STEM-PjBL Research in Physics Education by Country*

Indonesia has established academic cooperation only with Malaysia and Thailand as shown in Figure 4. Variations in national education policies and curricula influence the emphasis placed on STEM-PjBL learning. While countries like Indonesia and Malaysia have national policies supporting STEM education, others may lack similar initiatives. Furthermore, the lack of established academic networks across ASEAN countries limits the dissemination of knowledge and best practices in STEM-PjBL. This provides further opportunities for further research on inter-country academic cooperation in STEM-PjBL research in physics education. The keyword network can be visualized by using VOSViewer software with co-occurrence analysis type. The keyword network in the application of STEM integrated project based learning (STEM-PjBL) research in physics education is visualized in 14 clusters, as shown in Figure 5. Project-based learning is the most used keyword, which is 60 times or 25.75% of the total number of keywords that appeared. This keyword is directly related to the STEM and 21st century skills keywords which include critical thinking, creativity, collaboration, and communication. The color of each network varies with the year of the implementation of the keyword. The yellow color shows the use of keywords in the STEM-PjBL research in physics education on the latest. This proves that STEM-PjBL research is widely pursued to improve students' 21st century skills.

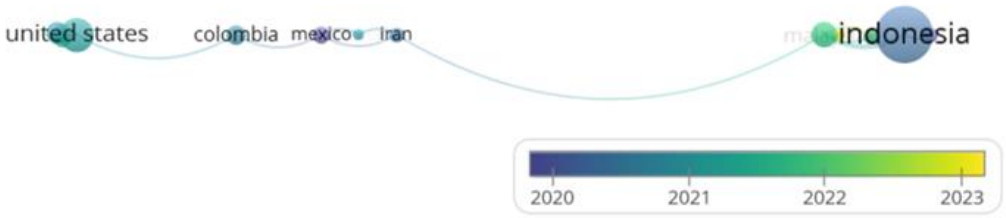


***Fig 4**. Cooperation Network of STEM-PjBL Research in Physics Education*

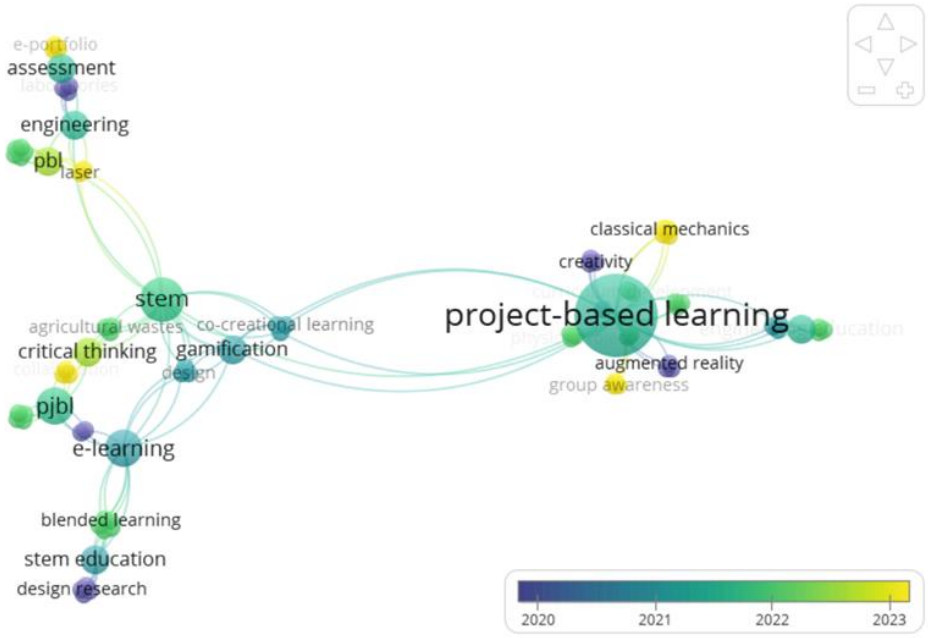


***Fig 5**. Keywords Network of STEM-PjBL Research in Physics Education*

Based on the results of the analysis, the most widely used type of quantitative research. This is because many researchers analyze the application of the STEM integrated project based learning (STEM-PjBL) as a means of improving 21st century skills. The most widely used research model is the quasi-experiment. Experimental research has a broad scope so that it can vary the complexity of the research variables. A quantitative research with quasi-experimental method was used to analyze students' creative thinking skills in momentum and impulse material through STEM integrated project based learning [27]. The implementation of the STEM-PjBL has a positive impact on improving students' creative thinking skills especially in physics learning.

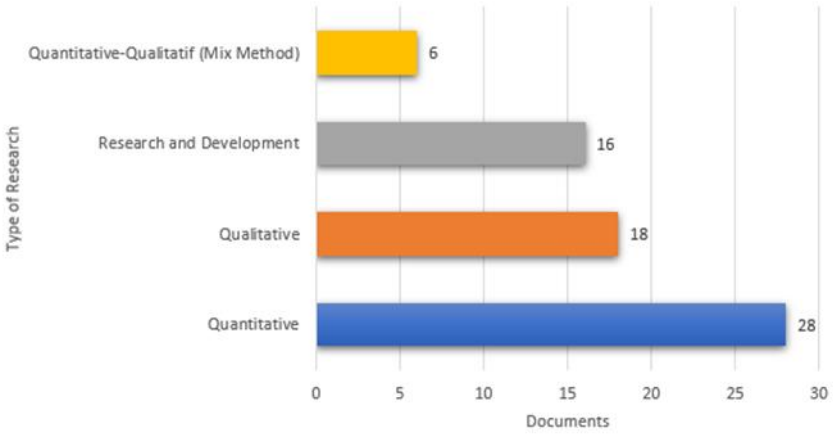


***Fig 6**. Type of STEM-PjBL Research in Physics Education*

The research subjects used in the articles studied can be seen in Figure 7. High school studens are the most widely used research subjects in this research topic. Many studies use small-scale samples of less than 50 respondents. STEM-PjBL is highly aligned with the principles of the Merdeka Curriculum and is particularly well-suited for high school students [28] [29]. In Merdeka Curriculum, students are encouraged to take an active role in their learning, and STEM-PjBL fosters this by allowing them to explore real-world challenges through projects [30] [31]. This approach engages their critical thinking, creativity, communication, collaboration, character, computational thinking, and problem-solving skills, which are essential skills for high school students.

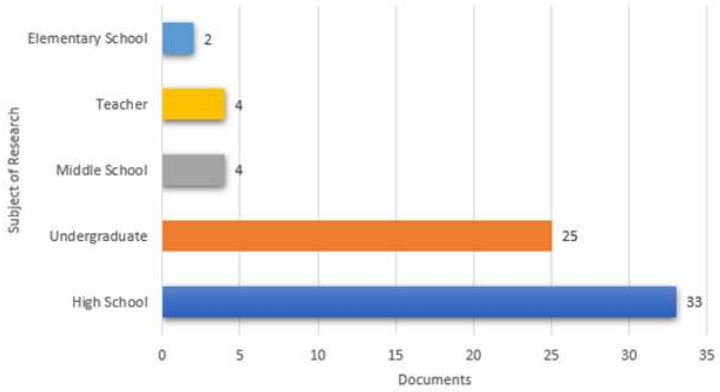


***Fig 7**. Subject of STEM-PjBL Research in Physics Education*

*Impact of STEM-PjBL on The Achievement of 21st Century Skills*

In the dynamic environment of modern education, adopting innovative teaching approaches is essential for preparing students to face future challenges. As education continues to adapt to the needs of the 21st century, integrating STEM disciplines into learning frameworks has gained significant attention. One effective approach that has emerged is STEM integrated project-based learning, commonly referred to as STEM-PjBL. Based on analysis results, STEM-PjBL can improve critical thinking, communication, creativity, collaboration, problem solving, character, and computational thinking in the physics learning [32] [33]. Thus, the STEM-PjBL STEM model is very much in line with the aim of the Merdeka Curriculum to create learning that is relevant to real life [34] [35]. This is because the STEM-PjBL model is able to provide new ideas and apply them in problem solving based on the results of critical and creative thinking and can create effective cooperation and communication in learning in producing products from the project. Based on the results of content analysis, STEM-PjBL is most widely used to improve the achievement of creativity skills as shown in Figure 8.

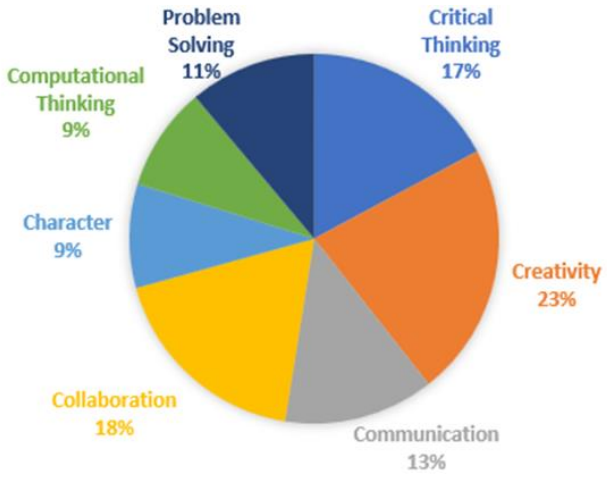


***Fig 8**. Analysis of the achievement of 21st Century skills*

The use of the Science, Technology, Engineering, and Mathematics (STEM) approach in the project-based learning model can improve students' logical thinking skills. STEM involves learners in metacognitive activities that challenge them to reflect on their own thinking processes. These metacognitive activities include the process of choosing, searching, asking, dividing, developing hypotheses, and the decision-making process [36]. Metacognitive is very much in line with the idea of Merdeka Curriculum, because this strategy emphasizes students to consciously determine, design, and reflect on their learning process [37]. In its implementation, the STEM-PjBL model provides a loop

for learners to understand the importance of integrating different disciplines and their applications in learning. Learning with the STEM-PjBL model creates real-life learning and can facilitate learners with direct experience through providing opportunities to construct their own knowledge independently or in groups through active and fun learning. Thus, the application of the STEM-PjBL learning model has a great opportunity to train students' 21st Century skills through the characteristics in its approach.

The STEM integrated project based learning (STEM-PjBL) is able to equip students to prepare themselves for learning in the 21st Century. The STEM-PjBL model is able to have a significant effect on 21st century skills. This is because the learning syntax in the project-based learning model helps students to improve their critical thinking, communication, creative, problem solving, character, computational thinking, and collaboration skills. There are five phases of the development of students' creative thinking in the project-based learning model, namely the reflection phase, research phase, discovery phase, application phase, and communication phase [38]. In the reflection phase, the teacher provides opening questions as a stimulus and initial stage to bring students into the topic of the problem. This can develop students' critical and creative thinking skills [39] [40]. At this stage, students are able to digest and understand the problem, convey information based on their own abilities and language and directly, think about what products can be made based on the questions asked.

The second phase is research. In this phase, students are directed to find information about the topic and discuss it with group members [41]. Students will try to develop ideas by analyzing various information from various literatures in groups. This activity can develop collaboration and creative thinking skills. The aspect of creative thinking skills developed is elaboration [42]. Furthermore, the third phase is discovery. Students discuss to develop a project design according to the agreement of each group [43]. This activity can improve students' critical and creative thinking skills because of the engineering design process to produce products related to science. The fourth phase is application, where students conduct experiments as project tasks according to an agreed timeline. This process can develop students' creative thinking skills because students can explain and evaluate phenomena by providing various answers and examples [44]. The aspects of creative thinking skills developed are flexible thinking, fluency, and elaboration. The last phase is the communication phase. Each group presents its project. This activity will train students' communication skills. Students are asked to be able to interpret data and evidence scientifically by drawing conclusions based on experiences when doing the project by explaining in detail, corecctly and coherently [45]. The presentation process optimizes various students skills namely, speaking skills, analysis skills, technology application skills, presentation skills, problem solving skills, and negotiation skills. At the end of the presentation, the teacher provides feedback related to the experimental project that has been carried out.

The STEM integrated project-based learning (STEM-PjBL) model not only prepares students for 21st century skills but also nurtures essential skills for future success. This model significantly enhances critical thinking, as students are required to analyze and evaluate complex problems from multiple perspectives [46] [47] [48]. Furthermore, STEM-PjBL promotes communication skills by encouraging students to present their findings and ideas effectively in both written and oral formats [49] [50] [51]. The model also cultivates creativity by giving students the freedom to explore innovative solutions during the discovery phase [27] [37] [52]. Problem-solving becomes a central focus, as learners are tasked with addressing real-world challenges that require thoughtful, evidence-based solutions [53] [54] [55]. Computational thinking is developed as students engage with technology and data analysis to solve these problems [56] [57] [58]. Character building is another important outcome of this model, as students learn resilience, responsibility, and perseverance throughout the learning process [59] [60] [61]. Collaboration is fostered as learners work together in teams, enhancing their ability to cooperate and contribute meaningfully to group efforts [48] [61]. The integration of technology in the STEM-PjBL model also helps students adapt to digital tools and platforms, preparing them for the increasingly digital workforce. The model's focus on real-world applications makes learning more relevant, motivating students to see the value of their education in everyday life. Finally, STEM-PjBL

provides opportunities for continuous reflection, allowing students to assess their progress and identify areas for improvement.

The STEM-PjBL approach is crucial for enabling students to master relevant disciplinary concepts while also providing them with real-world experiences that are applicable to their daily lives. This is in accordance with the learning goals of the Merdeka Curriculum [62]. By engaging in projects that require the integration of theory and practice, students learn to recognize the interconnectedness of science, technology, engineering, and mathematics as a cohesive and mutually reinforcing system. The integration of STEM in project-based learning models provides flexibility in instructional design. Teachers have the opportunity to design projects that are relevant to students' needs and the demands of the times, ultimately increasing the relevance of education to the workforce. Merdeka Curriculum's flexibility is perfectly aligned with STEM-PjBL, allowing educators to adapt projects to the needs and interests of students, as well as the evolving demands of society and the workforce. This relevance makes learning more meaningful, as students gain skills that are directly applicable to their future careers. By developing 21$^{st}$ century skills through STEM-PjBL, students in Indonesia are prepared to become individuals capable of adapting to various situations, including facing complex and multidisciplinary global challenges in the future. This approach also supports the development of character, responsibility, and effective communication skills, all of which are key elements in professional and personal success in the era of globalization and rapidly evolving technology.

In the future, further research can focus on the implementation of application of STEM-PjBL to the Merdeka Curriculum in various educational environments, including remote areas or schools with limited facilities, to identify the challenges and opportunities that arise in implementing this model. Additionally, research can explore how STEM-PjBL can be adapted to meet the diverse needs of individual students, including those with higher or lower skills in STEM. By conducting more in-depth research, it is hoped that new innovations can be discovered in developing more flexible and inclusive project-based curricula, as well as more effective learning strategies for developing 21st-century skills across various educational contexts.

## CONCLUSION AND SUGGESTION

The results of the systematic analysis of literature (SLR) from 2020 to 2024, the development of STEM-PjBL in Indonesia has increased significantly. This is in line with the efforts of the Indonesian government in improving the quality of education to ultimately produce a generation that has global competitiveness through Merdeka Curriculum. The implications that are often used on the results of the analysis are the type of quantitative research using the experimental method, the study of students or high school students with a small scale sample size of less than 50 respondents, and research that is widely used to analyze creativity skills. However, the STEM-PjBL model has proven effective in improving critical thinking, creativity, collaboration communication, problem solving, character, and computing thinking skills. There are several limitations to this research. Firstly, the use of a single Scopus database cannot possibly cover all scientific publications about STEM integrated project based learning (STEM-PjBL). The subsequent use of additional bibliographical research tools, such as the Web of Science and Google Scholar, will eliminate gaps in the analysis. Additionally, the analysis instrument used (VOS viewer software) has several functional limitations that few can overcome at this time, such as statistics of new authors published in various categories or statistics of new authors published in the year.

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