Volume 2 Issue 6 (December,2025) Pages 38-49
Journal of Pedagogi : Jurnal Pendidikan
ISSN: : 3046-9554 (Online)

Transforming STEM Learning through PBL to Improve Computational Thinking Skills

Uswatun Hasanah[1], Nuril Huda[2]
Universitas Jakarta (1)
UIN Maulana Malik Ibrahim Malang (2)
DOI: https://doi.org/10.62872/arcvet10

Abstrak
Transformasi pembelajaran STEM melalui pendekatan Problem-Based Learning (PBL) menjadi strategi penting untuk meningkatkan keterampilan computational thinking (CT) mahasiswa dalam menghadapi tuntutan era digital dan revolusi industri 4.0. Penelitian ini bertujuan menganalisis secara mendalam kontribusi PBL dalam pengembangan CT pada pendidikan tinggi Indonesia, terutama dalam konteks implementasi kebijakan Merdeka Belajar–Kampus Merdeka (MBKM). Namun, hingga kini masih belum jelas bagaimana model PBL dapat diimplementasikan secara efektif dalam pembelajaran STEM untuk mengoptimalkan pengembangan computational thinking mahasiswa di perguruan tinggi Indonesia. Permasalahan utama penelitian ini terletak pada belum terbangunnya kerangka pedagogis yang sistematis dalam mengintegrasikan PBL-STEM guna memperkuat komponen inti CT secara komprehensif. Oleh karena itu, penelitian ini mengkaji sejauh mana penerapan PBL mampu memperkuat kemampuan CT mahasiswa dalam konteks kurikulum Merdeka Belajar–Kampus Merdeka. Metode penelitian menggunakan pendekatan systematic literature review dengan menganalisis 35 publikasi akademik terindeks SINTA dan Scopus periode 2017–2024, serta dokumen kebijakan pendidikan nasional dan internasional. Hasil penelitian menunjukkan bahwa PBL secara konsisten memperkuat lima komponen utama CT, yaitu dekomposisi masalah, pengenalan pola, abstraksi, perancangan algoritma, dan evaluasi solusi iteratif. Integrasi PBL juga mendorong kolaborasi, kreativitas, dan kemampuan refleksi mahasiswa dalam menyelesaikan persoalan berbasis teknologi, sains, dan rekayasa. Meski demikian, implementasi PBL-STEM masih menghadapi tantangan berupa kesiapan dosen, kesenjangan fasilitas digital, dan kebutuhan rubrik asesmen CT yang komprehensif. Temuan ini menegaskan pentingnya penguatan kapasitas pedagogik dosen, penyediaan infrastruktur digital kampus, serta integrasi asesmen berbasis proses untuk mendukung keberlanjutan praktik PBL-STEM.

Kata Kunci: computational thinking, pendidikan tinggi, PBL, STEM.

Abstract
Transforming STEM education through Problem-Based Learning (PBL) has emerged as a central strategy for strengthening university students' computational thinking (CT) skills in response to the challenges of the digital age and Industry 4.0. This study provides a comprehensive analysis of how PBL supports CT development within Indonesian higher education, particularly in relation to the Merdeka Belajar–Kampus Merdeka curriculum reforms. However, it remains unclear how PBL can be effectively implemented within STEM education to systematically optimize the development of students' computational thinking. The core problem addressed in this study concerns the absence of a coherent pedagogical framework that integrates PBL-STEM to comprehensively foster key CT components. Accordingly, this study examines the extent to which the application of PBL strengthens university students' computational thinking within the context of the Merdeka Belajar–Kampus

DOI: https://doi.org/10.62872/arcvet10
Merdeka curriculum. Using a systematic literature review approach, the study synthesizes 35 peer-reviewed publications indexed in SINTA and Scopus from 2017 to 2024, along with relevant national and international education policy documents. The findings indicate that PBL effectively enhances the five core components of CT, namely problem decomposition, pattern recognition, abstraction, algorithmic design, and iterative evaluation. PBL also promotes students' creativity, collaboration, and reflective reasoning in addressing real-world, technology-driven problems across STEM disciplines. Nevertheless, challenges persist, including lecturer readiness, disparities in digital infrastructure, and the limited availability of standardized CT assessment frameworks. The study underscores the importance of strengthening pedagogical capacity, improving digital learning ecosystems, and adopting process-oriented assessment models to ensure sustainable PBL-STEM implementation in higher education.
Keywords: computational thinking, higher education, PBL, STEM.

Corresponding author : Uswatun Hasanah
Email Address : uswatun-hasanah@unj.ac.id
Received November 23, 2025, Accepted December 10, 2025, Published December 24, 2025

Introduction

The rapid advancement of digital technology in the 21st century has fundamentally transformed the demands placed on education systems worldwide. Higher education institutions are no longer expected merely to transmit disciplinary knowledge, but also to cultivate higher-order thinking skills that enable graduates to adapt to technological change, solve complex problems, and engage in continuous innovation. In the context of Industry 4.0 and the emerging paradigm of Society 5.0, universities are required to redesign their learning paradigms to ensure that students are equipped with cognitive, analytical, and technological competencies relevant to the digital economy. In Indonesia, this challenge is particularly significant as higher education institutions are expected to prepare graduates who can compete in an increasingly globalized and technology-driven labor market.

One of the key competencies widely recognized as essential in this context is computational thinking (CT). Computational thinking refers to the systematic ability to formulate problems, decompose complex situations into manageable components, identify patterns, apply abstraction, design algorithms, and evaluate solutions iteratively to achieve effective and efficient outcomes (Wing, 2017). Importantly, CT is not limited to programming or computer science; rather, it represents a universal cognitive framework that can be applied across disciplines to support structured reasoning and problem solving. UNESCO (2022) emphasizes that computational thinking constitutes a core component of modern digital literacy and should be integrated into learning across Science, Technology, Engineering, and Mathematics (STEM) as well as other academic fields. Consequently, the development of CT has become a strategic priority in higher education reform globally.

In Indonesian universities, the urgency of strengthening computational thinking has intensified alongside the integration of digital technologies in learning environments, the implementation of the Merdeka Belajar–Kampus Merdeka (MBKM) policy, and the rising expectations of industry for graduates with adaptive and innovative competencies. The MBKM policy explicitly encourages flexible curricula, project-based learning, interdisciplinary collaboration, and closer alignment between academic learning and real-world challenges. These policy directions implicitly demand learning approaches that go beyond content mastery and emphasize the development of transferable thinking skills such as CT. However, despite this growing recognition, the actual fulfillment of computational thinking competencies in Indonesian higher education remains uneven and, in many cases, suboptimal.

Empirical studies indicate that STEM learning in Indonesian universities often remains theoretical and teacher-centered, with limited opportunities for students to engage in authentic problem solving and active knowledge construction (Widodo et al., 2023). Traditional instructional models that prioritize lectures, individual assignments, and summative examinations tend to emphasize factual recall rather than analytical reasoning, abstraction, and algorithmic thinking. As a result, students may demonstrate surface-level understanding of concepts while lacking the ability to apply computational logic to complex and unfamiliar problems (Rahmawati & Supriyadi, 2021). This condition highlights a critical pedagogical gap between the intended learning outcomes related to CT and the dominant teaching practices in higher education.

DOI: https://doi.org/10.62872/arcvet10

It is important to note that computational thinking is not merely a technical skill associated with coding or software development. Rather, CT encompasses cognitive and strategic dimensions that require students to engage in collaborative inquiry, hypothesis testing, iterative refinement, and reflective evaluation (Grover & Pea, 2020). These dimensions cannot be effectively developed through passive learning approaches. Instead, they require learning environments that encourage exploration, experimentation, and interaction with real-world problems. Consequently, innovative pedagogical approaches are needed to ensure that CT can be meaningfully integrated into higher education curricula and translated into students' actual problem-solving capabilities.

Within this context, Problem-Based Learning (PBL) has emerged as a pedagogical approach that is highly relevant for strengthening students' computational thinking. PBL is characterized by the use of authentic, ill-structured problems as the starting point for learning, requiring students to work collaboratively, conduct independent investigations, and engage in critical reflection to construct knowledge and solutions (Hmelo-Silver, 2019). Through these processes, students are actively involved in identifying problems, analyzing information, designing solution strategies, and evaluating outcomes activities that closely align with the core components of computational thinking.

A growing body of research demonstrates that PBL can enhance creativity, deep conceptual understanding, and the ability to design solutions based on computational logic. Lee and Ko (2022), for example, found that engineering students who engaged in PBL-based programming and robotics projects showed significant improvements in decomposition, pattern recognition, and algorithmic thinking. Similarly, Grover and Pea (2020) argue that problem-based learning environments support the development of abstraction and synthesis skills by requiring students to connect concepts across contexts and evaluate alternative solution paths. These findings suggest that PBL provides a pedagogical structure that is inherently compatible with the development of CT.

In the Indonesian context, several studies also indicate the potential of PBL-STEM integration to improve computational thinking. Saputra et al. (2022) reported that the application of PBL in STEM courses increased student engagement, collaboration, and confidence in designing solutions using digital models and simulations. These outcomes are consistent with the objectives of the MBKM curriculum, which emphasizes experiential learning, interdisciplinary collaboration, and the application of knowledge to real-world challenges. By situating learning within meaningful problem contexts, PBL enables students to perceive the relevance of computational thinking beyond abstract academic exercises.

Globally, the effectiveness of PBL in strengthening computational thinking has been documented across various higher education contexts. Studies conducted in Korea (Lee & Ko, 2022), the Middle East (Al-Momani et al., 2023), and other regions demonstrate that PBL contributes not only to technical skill development but also to broader digital literacy and problem-solving competencies. These international findings reinforce the view that PBL can serve as a powerful pedagogical mechanism for preparing students to face future technological challenges. Nevertheless, the transferability of these findings to the Indonesian higher education context cannot be assumed without careful examination.

Despite the promising evidence, research on the implementation of PBL-STEM to strengthen computational thinking in Indonesian higher education remains limited and fragmented. Widodo et al. (2023) highlight that most existing studies in Indonesia focus on primary and secondary education, leaving a significant gap at the university level. Moreover, studies conducted in higher education settings often emphasize technical outputs, such as coding proficiency or project completion, without comprehensively assessing the conceptual and strategic dimensions of CT, including abstraction, debugging strategies, and algorithmic evaluation (Saputra et al., 2022). This narrow focus risks reducing CT to a set of technical skills rather than recognizing it as a complex cognitive process.

Another critical gap concerns the role of the digital learning ecosystem in supporting PBL-STEM implementation. International literature indicates that the effectiveness of PBL in developing computational thinking is strongly influenced by the availability of digital tools, simulation platforms, learning analytics, and collaborative technologies (UNESCO, 2022; Grover & Pea, 2020). However, many Indonesian universities face challenges related to unequal access to digital laboratories, limited use of computational platforms, and insufficient integration of technology into learning design. As a result, PBL activities may be implemented in a conventional manner that does not fully engage students in computational practices.

DOI: https://doi.org/10.62872/arcvet10

The urgency of this research, therefore, lies not only in examining whether PBL improves computational thinking, but also in understanding how pedagogical transformation in STEM learning can be implemented systematically within Indonesian higher education. The novelty of this study resides in its integrative approach, which examines the relationship between PBL, STEM integration, and computational thinking competencies within the framework of the MBKM policy. By synthesizing empirical findings and policy perspectives, this study seeks to move beyond fragmented evaluations and provide a holistic understanding of how PBL-STEM can be designed to support CT development effectively.

Furthermore, this study addresses a critical pedagogical problem arising from the mismatch between expected learning competencies and actual classroom practices. Despite the widespread recognition of computational thinking as a key 21st-century skill, current STEM learning practices in Indonesian universities often fail to facilitate the systematic development of decomposition, abstraction, pattern recognition, algorithm design, and iterative problem-solving skills. PBL-STEM initiatives, when implemented without alignment to CT assessment frameworks and digital ecosystem support, tend to produce inconsistent learning outcomes and limited evidence of sustained CT mastery across disciplines. This condition raises an essential question: how can PBL be designed and implemented to function not merely as an engaging instructional strategy, but as a structured pedagogical mechanism for strengthening computational thinking?

Addressing this question is essential to ensure that PBL contributes meaningfully to the goals of the Merdeka Belajar–Kampus Merdeka curriculum innovation. Accordingly, the purpose of this study is to analyze how the PBL model can optimize computational thinking development within STEM learning in Indonesian universities, identify key pedagogical mechanisms that support its effectiveness, and formulate project-based curriculum implementation strategies that enhance students’ readiness to face technological and digital-based workforce demands.

Pedagogical transformation through the integration of STEM and PBL must be understood as a systemic process involving learning design, technological support, lecturer competencies, and institutional readiness. In Indonesia, higher education institutions face the challenge of adapting curricula to accommodate contextual, collaborative, and digitally mediated learning experiences. However, not all study programs have succeeded in integrating STEM and PBL approaches consistently. Many courses continue to rely on direct instruction and theory-oriented assessment, resulting in uneven development of students’ computational thinking competencies (Widodo et al., 2023). This situation underscores the need for a deeper understanding of how PBL, STEM, and CT interact within the university learning environment.

UNESCO (2022) emphasizes that CT skills are inherently interdisciplinary and should be developed through authentic, problem-based, and collaborative learning experiences. As a metacognitive skill set involving abstraction and algorithmic reasoning, CT cannot flourish within passive instructional models. Grover and Pea (2020) further argue that students must be provided with opportunities to explore ideas, test hypotheses, analyze errors, and reflect on their thinking processes through iterative learning cycles. PBL, therefore, serves as a pedagogical mechanism that enables students to build problem-solving logic in a structured yet flexible manner. Empirical evidence from Latin et al. (2022) supports this view, showing that students engaged in project- and problem-based learning demonstrate stronger decomposition and reasoning skills than those in conventional learning environments.

Beyond cognitive development, computational thinking is also closely linked to affective dimensions such as learning motivation, self-confidence, and creativity. Saputra et al. (2022) found that students involved in PBL-STEM projects exhibited greater confidence in applying computational concepts, mathematical modeling, and digital simulations to real-world problems. These experiences foster emotional and intellectual engagement, particularly when students address issues related to sustainability, health technology, or digital system design. Thus, PBL-STEM integration has the potential to cultivate not only CT but also reflective, innovative, and collaborative problem solvers.

In Indonesia, national policies emphasizing digitalization and innovation further reinforce the importance of CT development in higher education. However, institutional readiness varies considerably, influenced by factors such as digital infrastructure, lecturer expertise, industry partnerships, and assessment practices. Widodo et al. (2023) note that many lecturers encounter difficulties in implementing authentic CT assessments due to limited experience and the absence of standardized rubrics. Consequently, curriculum design must incorporate systematic support for

DOI: https://doi.org/10.62872/arcvet10

lecturer capacity building, the development of CT-oriented modules, and cross-program collaboration to create an integrated learning ecosystem.

Finally, this study seeks to contribute to the higher education literature in Indonesia by offering a comprehensive analysis of how PBL can transform STEM learning to holistically improve computational thinking. By addressing pedagogical design, technology integration, assessment strategies, and institutional readiness, this research aims to support the development of policies and practices that prepare students to become adaptive, creative, and computationally competent graduates capable of responding to global technological challenges.

Method

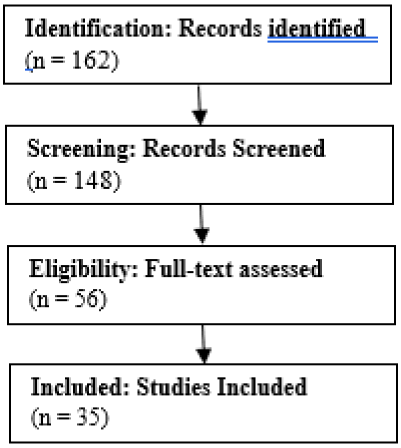
This study uses a mixed literature review approach with a descriptive qualitative orientation that emphasizes theoretical analysis and synthesis of empirical research results related to the integration of Problem-Based Learning (PBL) in STEM learning to improve computational thinking (CT) skills in higher education. This approach was chosen because the issue of CT is a multidisciplinary field that must be analyzed from the perspectives of curriculum, pedagogy, technology, and higher education policy. According to Creswell (2021), a descriptive qualitative approach allows for in-depth exploration of educational phenomena through the interpretation of previous research results and an understanding of the context of learning implementation. To strengthen the academic foundation, the literature analysis refers to international and national research published between 2017 and 2024, including Scopus-indexed journals, SINTA, and UNESCO and Kemendikbudristek publications.

To ensure the rigor and relevance of the literature synthesis, explicit inclusion and exclusion criteria were applied. The inclusion criteria comprised: (1) peer-reviewed journal articles indexed in Scopus or SINTA; (2) publications between 2017 and 2024; (3) studies focusing on Problem-Based Learning, STEM education, and computational thinking in higher education contexts; and (4) empirical or conceptual studies that explicitly discussed CT components such as decomposition, abstraction, pattern recognition, algorithm design, or evaluation. Articles were excluded if they: (1) focused solely on primary or secondary education; (2) addressed CT only as programming skills without pedagogical discussion; (3) lacked clear methodological descriptions; or (4) were opinion-based, non-scholarly, or duplicated across databases. This selection process reduced subjectivity and ensured that the synthesized findings reflected robust and relevant evidence.

The data collection process was carried out through systematic literature tracing of scientific articles, proceedings, and policy documents related to PBL, STEM, CT, and the Indonesian higher education curriculum. Articles were searched using the keywords "Problem-Based Learning," "STEM Higher Education," "Computational Thinking," and "Merdeka Belajar Higher Education Curriculum," then selected using an approach based on content acceptability and educational relevance. The selection strategy followed the principle of evidence synthesis as suggested by Snyder (2019), covering the process of identification, screening, evaluation of article quality, to the finalization of the literature used. Dominant international literature was obtained through Scopus and Google Scholar, while national literature was obtained through the SINTA database and university repositories.

Data analysis was conducted through content-thematic analysis to find conceptual and practical patterns in the implementation of PBL-STEM to develop CT. The analysis process followed the stages outlined by Miles, Huberman, and Saldaña (2020), namely data condensation, data presentation, and conclusion drawing, with validity maintained through triangulation of sources and conceptual cross-verification. The interpretation of the results was carried out by considering the context of Indonesian higher education in the Merdeka Belajar (Freedom of Learning) policy, the development of learning technology, and the readiness of project-based curricula. With this method, the study is expected to provide a comprehensive picture of effective pedagogical mechanisms for improving CT through PBL-STEM learning.

DOI: https://doi.org/10.62872/arcvet10



Results and Discussion

Conceptualization of Computational Thinking in Higher Education STEM Learning

Computational thinking (CT) has evolved into one of the core competencies in 21st-century education, especially in the context of digital transformation and technology-based economies. Wing (2017) defines CT as a cognitive process that involves the ability to systematically formulate problems, build relevant data representations, develop solution algorithms, and repeatedly assess the efficiency of solutions. This perspective positions CT not merely as a technical skill or programming ability, but as a universal framework of thinking that can be applied to solve various complex problems in academic and professional life. In the context of higher education, CT is the foundation that supports the development of students' problem-solving, analytical reasoning, creativity, and innovation skills (Grover & Pea, 2020). This becomes even more relevant with the introduction of the Merdeka Belajar–Kampus Merdeka (MBKM) policy, which places the mastery of future competencies as one of the main objectives of higher education in Indonesia (Kemendikbudristek, 2022).

CT skills have several core dimensions, including decomposition, pattern recognition, abstraction, algorithmization, and evaluation (UNESCO, 2022). In higher education, these dimensions are important because advanced academic activities require the ability to simplify complex problems into clearly defined sub-problems, formulate patterns of relationships between variables, develop mathematical or algorithmic models, and test alternative solutions. According to Lee and Ko (2022), students who master CT show a higher tendency to produce logical, innovative, and efficient solutions, especially in the fields of engineering, education, and computer science. This shows that CT is not just an additional skill, but an epistemological foundation that needs to be instilled through a systemic and authentic learning approach, especially in STEM-based programs.

However, in the Indonesian context, the application of CT in higher education is not yet evenly distributed. Widodo et al. (2023) note that many universities still focus on traditional learning approaches that emphasize content delivery rather than developing students' cognitive abilities through investigative and project-based approaches. As a result, students often have theoretical knowledge but lack the ability to apply computational principles to solve real problems in a multidisciplinary context. Saputra et al. (2022) found that engineering and technology education students at several universities in Indonesia still face difficulties in abstracting and building solution algorithms even though they have taken courses related to basic programming. These findings indicate a gap between the formal curriculum and the pedagogical strategies applied by lecturers, particularly in the integration of CT in learning activities.

In global literature, CT has been recognized as a competency that can be developed through various active learning approaches, such as project-based learning, collaborative learning, and problem-based learning (PBL) (Grover & Pea, 2020; Lee & Ko, 2022). PBL, in particular, is highly compatible with the characteristics of CT because it places students in real-world situations that require systematic thinking, experimentation, decision-making, and reflection. Hmelo-Silver (2019)

DOI: https://doi.org/10.62872/arcvet10

explains that PBL provides space for students to develop CT through the steps of problem identification, data analysis, alternative solution design, prototype development, and solution success evaluation. This approach has the potential to overcome the limitations of traditional lecture methods that have dominated higher education.

The context of implementing PBL-STEM for CT is not only a matter of pedagogy, but also relates to curriculum design, learning culture, and the readiness of higher education institutions. According to UNESCO (2022), the successful development of CT in students requires systemic support that includes the provision of digital resources, training for lecturers in innovative pedagogy, and clear assessment standards. In Indonesia, educational transformation in the digital realm and the implementation of project-based learning have become the focus of the Ministry of Education, Culture, Research, and Technology's (2022) policies. However, the success of this implementation is highly dependent on the ability of higher education institutions to integrate the CT curriculum into STEM courses, provide collaborative practice spaces, and adapt supporting technologies such as simulations, learning management systems, and visual programming platforms.

CT should not only be part of the formal curriculum, but also practiced in authentic learning situations. Several studies show that real-world problem-solving activities, IoT device simulations, data analysis, and simple algorithm development can increase student engagement and conceptual understanding of CT (Al-Momani et al., 2023). Conversely, passive instructional approaches that rely on verbal explanations and abstract examples tend to result in superficial adaptation and shallow understanding of CT principles. In addition, evaluation approaches that combine performance-based assessment and CT rubrics have been shown to increase students' awareness of their thinking processes (Widodo et al., 2023). This is in line with constructivist theory, which emphasizes the importance of active learning in building knowledge structures.

In the context of MBKM, the integration of CT through PBL-STEM is also relevant to support the development of soft skills and transferable competencies. The MBKM curriculum emphasizes flexibility, industry collaboration, and real problem solving as strategies to prepare students for the dynamics of the modern world of work. Thus, mastery of CT not only supports technical skills but also communication, project management, and cross-disciplinary collaboration skills. Lee and Ko (2022) state that students who learn CT through the PBL approach show an increase in teamwork skills and the ability to validate solutions through scientific argumentation, which are important skills in a culture of research and technological innovation.

Finally, based on existing research findings and literature, it can be concluded that CT is a strategic competency for the development of the quality of Indonesian higher education graduates in facing the challenges of technology and globalization. However, the success of CT implementation is highly dependent on pedagogical transformation and learning strategies that accommodate problem-solving approaches, collaboration, and the development of algorithmic thinking. PBL in the context of STEM is one of the most promising strategies to achieve this goal, but its success requires institutional support, lecturer readiness, and a measurable and sustainable assessment framework. Thus, the development of CT is not only a curriculum agenda, but also an agenda for the transformation of Indonesian higher education to produce a generation that is adaptive, creative, and competent in the global technological landscape.

Implementation of PBL-STEM and Mechanisms for Strengthening Students' Computational Thinking

The implementation of Problem-Based Learning (PBL) in STEM learning in higher education in Indonesia shows strategic potential to support the strengthening of computational thinking (CT) skills. In principle, PBL provides a learning environment that places students as active agents who solve authentic and complex problems, encouraging them to analyze issues systematically, develop solution strategies, and think logically and algorithmically (Hmelo-Silver, 2019). This model is in line

DOI: https://doi.org/10.62872/arcvet10

with the demands of STEM epistemology, which integrates the concepts of science, technology, engineering, and mathematics to produce innovation-based solutions. Thus, PBL is not only a learning method but also a medium for building higher-order cognitive competencies that place CT at the core of the learning process.

In the context of Indonesian universities, the application of PBL-STEM is translated through various forms of academic activities such as interdisciplinary projects, technical simulations, prototype design, and algorithm modeling for solving real-world problems. For example, in engineering and technology education study programs, students are directed to develop information technology-based solutions that reflect an understanding of problem decomposition, pattern identification, algorithm design, and iterative solution testing (Saputra et al., 2022). These steps are in line with the computational thinking framework that places the problem-solving cycle at the core of scientific learning. Meanwhile, in mathematics and science education programs, the integration of PBL enables students to understand quantitative problems through algorithmic representations and data-based simulations that strengthen their abstraction and generalization skills (Widodo et al., 2023).

In addition, the implementation of PBL-STEM requires a learning environment that supports collaboration, creativity, and strong intellectual interaction. This learning model encourages students to work in small groups, gather information from various sources, discuss solutions, and make argumentative presentations on their solution designs. These collaborative activities are in line with the findings of Grover and Pea (2020), who emphasize that CT develops optimally when students engage in intellectual discussions that require them to logically break down problem structures and assess the feasibility of solutions through comparison of alternatives. In Indonesia, PBL-STEM learning is further strengthened by the Merdeka Belajar Kampus Merdeka (MBKM) policy, which encourages project-based learning across study programs, collaboration with industry, and the resolution of real-world problems in the workplace (Kemendikbudristek, 2022).

However, the successful implementation of PBL-STEM is not without methodological and institutional challenges. Several lecturers reported obstacles in designing authentic problems that truly connect STEM concepts with the CT context in depth (Rahmawati & Supriyadi, 2021). In addition, CT assessment remains a serious problem because there is no consistent assessment rubric that can be widely adopted by lecturers. UNESCO (2022) emphasizes that CT evaluation needs to use a multimodal approach that measures cognitive, affective, and social-collaborative aspects. Thus, the integration of performance-based assessment, algorithmic analysis rubrics, and reflective evaluation is a must to ensure that students' CT development is not only measured by technical outputs such as computer programs but also by their thought processes in solving problems.

To understand the characteristics of CT in the context of PBL-STEM, the following table presents the core indicators of CT in a university setting:

CT Component	**Operational Skills in PBL-STEM Projects**	**Expected Student Demonstrations**
Decomposition	Breaking complex problems into manageable sub-problems	Students define tasks and assigns roles in group projects
Pattern Recognition	Identifying repeated structures or relationship	Students compare multiple solutions or case patterns
Abstraction	Filtering essential details and ignoring irrelevant data	Students build conceptual models or simplified system diagrams
Algorithm Design	Developing step-by-step problem solving logic	Students create flowcharts or pseudocode before implementation
Debugging & Evaluation	Testing, revising, and	Students iterate prototypes

DOI: https://doi.org/10.62872/arcvet10

	validating solutions	and evaluate performance

Sources: Wing (2017); Grover & Pea (2020); Lee & Ko (2022)

The table shows that developing CT requires a systematic approach to learning, so that academic tasks focus not only on the final output, but also on the cognitive processes that students use to arrive at a solution. PBL allows students to internalize this process because each stage of learning requires students to reflect, develop strategies, and test hypotheses through experimentation. Latin et al. (2022) emphasize that CT is not only a technical matter but also a metacognitive practice that requires time and structured practice in an experience-oriented learning context.

Equally important, the integration of learning technology in the application of PBL-STEM in higher education provides essential support for CT development. Digital simulation platforms, virtual labs, and microcontroller applications such as Arduino or Microbit have been used to enhance technology-based learning experiences and facilitate students in designing algorithmic solutions (Al-Momani et al., 2023). The use of this technology not only improves the accuracy of solution implementation but also fosters students' ability to see the relationship between computational theory and technical implementation in the real world. However, Rahmawati and Supriyadi (2021) caution that reliance on visual software alone without a deep understanding of algorithmic principles can hinder the development of students' abstraction skills. Thus, a balance between the use of simulation technology and manual exploration is necessary to ensure that students understand the basic intuition of computation.

By combining collaborative learning, learning technology, and process-based assessment, PBL-STEM can be a transformative strategy in improving students' CT in Indonesian universities. However, the effectiveness of this strategy requires institutional support in the form of lecturer training, learning module development, and academic quality assurance policies that integrate CT into the curriculum and assessment structure. Research by Widodo et al. (2023) shows that higher education institutions that implement systemic support experience higher increases in student CT achievement than institutions that only implement partial changes in learning methodology. Therefore, the sustainability of PBL-STEM implementation requires strategic collaboration between academics, university management, and external stakeholders such as industry and research institutions.

Despite the widely reported benefits of PBL-STEM for enhancing computational thinking, the literature also reveals important limitations that warrant critical attention. Many studies tend to portray PBL as inherently effective without sufficiently examining the quality of problem design, depth of student engagement, or consistency of CT assessment practices. In several cases, improvements in CT are inferred from increased student activity or project completion rather than from rigorous evaluation of abstraction, algorithmic reasoning, and iterative problem refinement. Moreover, the assumption that collaborative and technology-supported learning automatically leads to stronger CT overlooks variations in students' cognitive readiness and lecturers' facilitation skills. Without explicit scaffolding and aligned assessment rubrics, PBL-STEM risks becoming procedurally active but cognitively shallow, producing engagement without sustained CT mastery. These findings suggest that PBL-STEM effectiveness is conditional rather than universal, dependent on pedagogical design quality, institutional support, and assessment coherence.

Challenges in Implementing PBL-STEM and Strategies for Strengthening Students' Computational Thinking

Although PBL-STEM has strong potential to improve computational thinking (CT), its implementation in higher education in Indonesia faces various structural, pedagogical, and cultural challenges. One of the main challenges is the readiness of lecturers and institutions to design problem-based learning that is aligned with CT competencies. PBL requires lecturers to change their role from a source of knowledge to a facilitator, while also designing complex and relevant authentic problems related to the students' discipline (Hmelo-Silver, 2019). However, Rahmawati and Supriyadi (2021) found that some lecturers still find it difficult to design problems that require students to perform in-depth decomposition, abstraction, and algorithmization. This obstacle is exacerbated by limited access to STEM and CT pedagogy training, as well as the lack of standardized CT assessment rubrics at Indonesian universities (Widodo et al., 2023).

In addition to pedagogical constraints, technological challenges also limit the effectiveness of PBL-STEM. Although the digital transformation of higher education has developed rapidly after the

DOI: https://doi.org/10.62872/arcvet10

pandemic, not all study programs have equal access to digital laboratories, learning analytics, IoT devices, and programming platforms to support experimental learning, which is essential for CT development (Kemendikbudristek, 2022). Al-Momani et al. (2023) emphasize that access to devices and the technological literacy of lecturers and students significantly affect the success of computational project-based learning. The inequality of facilities between universities also widens the gap in the quality of CT development, especially in regional universities that face funding and human resource constraints.

From the students' perspective, challenges also arise from learning styles and cognitive readiness. Students who are accustomed to passive, memorization-oriented learning often find it difficult to adapt to the exploratory and highly initiative-driven demands of PBL (Saputra et al., 2022). CT requires discipline in thinking, resilience to failure, and a habit of reflection in the process of debugging logic and solutions. Latin et al. (2022) show that students who are not accustomed to iterative processes often feel frustrated when encountering program errors or prototype failures, thus requiring strong instructional support and mentoring. This shows that CT learning is not only a matter of curriculum, but also a transformation of the learning culture of students to be more proactive, resilient, and collaborative.

Another challenge lies in the assessment system, which does not yet fully accommodate the characteristics of CT. Many universities still rely on written exams or final assignments based on finished products, without comprehensively measuring students' thinking processes (Widodo et al., 2023). In fact, CT requires a comprehensive evaluation of the process, reflection, and solution improvement strategies. UNESCO (2022) recommends multimodal assessments that measure CT indicators through performance-based rubrics, reflection journals, algorithmic concept maps, and iterative project assessments. Without well-developed rubrics, lecturers tend to assess technical outputs alone and fail to capture the complexity of students' CT abilities.

To overcome these obstacles, strategies to strengthen the implementation of PBL-STEM for CT need to be carried out through a systemic approach. First, strengthening lecturers' pedagogical capacity through regular training, workshops, and teaching clinics based on CT and STEM is necessary so that lecturers are able to design authentic problems, facilitate collaborative learning, and conduct authentic assessments. Grover and Pea (2020) emphasize that the successful implementation of CT depends on the readiness of educators to understand the conceptual framework of CT and apply it consistently in the curriculum. Second, universities need to develop a learning technology ecosystem by providing computing laboratories, micro-computing platforms, and integrating analytics-based learning management systems to monitor students' CT development (Al-Momani et al., 2023).

Furthermore, strategies to protect and strengthen the learning culture of students need to be implemented through the provision of scaffolding, peer mentoring, and project-based learning communities. A study by Lee and Ko (2022) shows that students who are involved in learning communities and algorithmic discussions experience a significant increase in CT confidence and debugging skills. In Indonesia, the concept of *Project-Based Kampus Merdeka* can be a platform for the implementation of learning communities across study programs and industries. This collaborative program not only provides real project experience but also encourages students to build professional networks that are relevant to the needs of the digital industry.

To clarify effective implementation strategies, the following table presents systemic challenges and solutions for applying PBL-STEM for CT:

Table 2. Challenges and Strategic Solutions for PBL-STEM Implementation to Strengthen CT

Challenge Category	Spesific Issues	Strategic Solutions
Pedagogical	Difficulty designing authentic CT-friven PBL tasks	Lecturer training, co-teaching, PBL design clinics
Assessment	Lack of CT-aligned rubrics	Develop CT rubrics, portfolio & reflection assessment
Technological	Limited access to labs & digital tools	Provide microcomputing kits, platform sharing, cloud labs
Student Mindset	Low resilience, passive learning habits	Peer mentoring, scaffolded inquiry, reflective practices

DOI: https://doi.org/10.62872/arcvet10

Institutional Policy	Fragmented curriculum support	Policy integration in MBKM, interdisciplinary PBL programs

Sumber: Grover & Pea (2020); Widodo et al. (2023); UNESCO (2022); Al-Momani et al. (2023)

The implementation of this strategy is expected to produce a learning ecosystem that can comprehensively accommodate the dynamics of CT. In addition to managerial and pedagogical aspects, the success of CT transformation through PBL-STEM also depends on the formation of an academic culture that values exploration, failure as a learning process, and cross-disciplinary collaboration. Rahmawati and Supriyadi (2021) emphasize that failure-based iteration is an important part of the computing learning process because debugging and refinement skills are at the core of CT. Thus, universities must create a safe and supportive environment for students to experiment and develop creative solutions without fear of failure.

Overall, the implementation of PBL-STEM to strengthen CT among Indonesian university students is an educational transformation process that requires the commitment of multiple parties, from lecturers, students, university management, to national education policy makers. With the support of the Merdeka Belajar (Freedom of Learning) policy and the strengthening of the digital ecosystem, Indonesia has a great opportunity to accelerate the development of technological and innovation competencies among students. However, this success requires consistency, collaboration, and the application of holistic assessments so that CT does not merely become a curriculum buzzword but is realized in students' actual ability to think systematically, algorithmically, and critically in facing the challenges of the modern world.

Conclusion

The transformation of STEM learning through the Problem-Based Learning (PBL) approach has proven to be a relevant and effective pedagogical strategy in improving the computational thinking (CT) skills of higher education students in Indonesia. PBL provides authentic learning experiences based on real-world problems that encourage students to develop skills in decomposition, pattern recognition, abstraction, algorithm design, and solution evaluation as the core CT competencies according to the UNESCO (2022) and Wing (2017) frameworks. The integration of PBL-STEM is in line with the direction of the Merdeka Belajar–Kampus Merdeka (MBKM) policy, which emphasizes project-based learning, cross-disciplinary collaboration, and innovative problem-solving skills needed by the digital technology-based industry.

However, the implementation of PBL-STEM faces challenges in the form of lecturer readiness, technological limitations, low cognitive readiness of students for exploratory learning, and limited comprehensive CT assessment. Therefore, the success of this approach requires systemic support in the form of pedagogical training for lecturers, strengthening of campus digital infrastructure, application of process-based CT assessment rubrics, and the establishment of a collaborative learning ecosystem that values failure as part of the learning process. Through institutional commitment, academic collaboration, and national policy support, PBL-STEM learning has the potential to become a strategic foundation for producing graduates who are competent, innovative, and adaptive to the dynamics of future technology.

Long-term empirical studies are needed on the effectiveness of PBL-STEM in improving cross-disciplinary CT, exploring the role of AI technology in computational learning, and developing a digital portfolio-based CT assessment model for higher education institutions.

Based on these findings, several practical recommendations can be proposed for higher education stakeholders in Indonesia. Universities should prioritize the systematic integration of PBL-STEM into curricula by aligning course learning outcomes with explicit computational thinking indicators and embedding project-based activities across semesters. Lecturer professional development programs need to focus on designing authentic problem scenarios, facilitating collaborative inquiry, and implementing process-oriented CT assessment using clear rubrics and digital portfolios. At the institutional level, investment in digital infrastructure, such as virtual laboratories, microcontroller kits, and learning management systems with analytics features, is essential to support sustained PBL-STEM implementation. Collaboration with industry, schools, and research centers should be

DOI: https://doi.org/10.62872/arcvet10

strengthened to provide real-world problem contexts and ensure that CT-oriented STEM learning remains relevant to technological and labor market developments. Policymakers are also encouraged to provide incentives, guidelines, and monitoring mechanisms that support the institutionalization of PBL-STEM as a strategic vehicle for cultivating CT competencies in higher education.

Bibliography

Al-Momani, M., Bataineh, R., & Aljarrah, A. (2023). Enhancing computational thinking through microcontroller-based STEM projects. Journal of STEM Education, 24(2), 55–68.

Chen, Y. (2021). Project-based learning and digital capabilities. Education and Information Technologies, 26(6), 7983–8004.

Creswell, J. W. (2021). Qualitative inquiry and research design (4th ed.). Sage.

Grover, S., & Pea, R. (2020). Computational thinking: A competency whose time has come. Educational Researcher, 49(4), 258–266.

Hmelo-Silver, C. E. (2019). The learning-sciences perspective on PBL. Educational Psychology Review, 31, 239–243.

Kemendikbudristek. (2022). Kebijakan Merdeka Belajar–Kampus Merdeka. Jakarta: Kemendikbudristek RI.

Kim, S., & Park, J. (2019). CT for future engineers. IEEE Access, 7, 10288–10296.

Latin, R., Putra, D., & Manopo, M. (2022). Enhancing computational thinking through project-based learning. International Journal of Instruction, 15(2), 501–518.

Lee, J., & Ko, Y. (2022). Effects of PBL on computational thinking in engineering education. Computer Applications in Engineering Education, 30(5), 1450–1466.

Miles, M. B., Huberman, A. M., & Saldaña, J. (2020). Qualitative data analysis (4th ed.). Sage.

OECD. (2020). AI and the Future of Skills. OECD Publishing.

Pratama, R., & Ismail, M. (2022). Collaborative PBL and CT skills. Jurnal Teknologi Pendidikan, 9(2), 123–134.

Rahmawati, F., & Supriyadi, T. (2021). Problem-based learning and CT in Indonesian higher education. Jurnal Pendidikan Teknologi dan Kejuruan, 27(3), 345–359.

Rizal, A., & Hidayat, T. (2023). Penerapan CT dalam kurikulum Merdeka. Jurnal Pendidikan Indonesia, 12(1), 88–102.

Saputra, H., Fadhilah, R., & Nurhayati, E. (2022). PBL-based STEM to foster computational thinking in engineering. Jurnal Pendidikan Teknologi Informasi, 8(1), 15–29.

Snyder, H. (2019). Literature review as a research methodology. Journal of Business Research, 104, 333–339.

Suwono, H., et al. (2020). STEM education in Indonesian universities. Jurnal Pendidikan Biologi, 11(1), 14–22.

UNESCO. (2022). Digital learning and computational thinking competency framework. UNESCO Publishing.

UNESCO Bangkok. (2021). STEM and digital innovation in Asia. UNESCO.

Widodo, A., Ramdani, R., & Priatna, M. (2023). Challenges of CT-STEM implementation in Indonesian universities. Jurnal Ilmu Pendidikan, 29(2), 177–190.

Wing, J. (2017). Computational thinking: What and why? Communications of the ACM, 60(1), 32–35.

Zawacki-Richter, O., et al. (2020). Systematic review methodology in education research. Review of Educational Research, 90(4), 1–35.