BIO-INOVED
Jurnal Biologi-Inovasi Pendidikan
Volume 8, Issue 1, February 2026 page. 65-73

P-ISSN : 2684-9062 | E-ISSN : 2714-9803
https://ppjp.ulm.ac.id/journal/index.php/bino
DOI: 10.20527/bino.v8i1.21867

Systematic literature review: Analysis potential implementation of STEAM in the Merdeka Curriculum for senior high school biology

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Article Information

Keyword:
Biology; STEM education; Merdeka Curriculum; Systematic literature review

Kata Kunci:
Biologi; Pendidikan STEM; Kurikulum Merdeka; Tinjauan pustaka sistematis

History:
Received : 09/02/2025
Revised : 16/01/2026
Accepted : 18/01/2026
Published : 09/02/2026

Abstract

Science, Technology, Engineering, Arts, and Mathematics (STEAM) learning is an educational approach that integrates science, technology, engineering, art, and mathematics to address real-life problems. It aims to develop students' critical, creative, communicative, and collaborative skills in line with 21st-century competencies. This study aims to explore the potential and reported trends of implementing STEAM in the Independent Curriculum in biology learning in Indonesia, particularly in underdeveloped areas, rather than to determine its direct effectiveness. A Systematic Literature Review (SLR) was conducted using Google Scholar to identify relevant articles published between 2018 and 2024. The selection process involved screening for relevance to STEAM-based learning in biology and applying inclusion criteria such as focus on senior high school education and Indonesian context. Out of 10 selected articles, the analysis was performed using thematic synthesis to identify common patterns and trends. The results indicate that the Independent Curriculum has the potential to support STEAM-based learning, even in disadvantaged areas, and that this integration can foster the development of students' competencies in accordance with 21st-century learning goals.

Abstrak. *Pembelajaran Science, Technology, Engineering, Arts, and Mathematics (STEAM) adalah pendekatan pendidikan yang mengintegrasikan sains, teknologi, teknik, seni, dan matematika untuk mengatasi masalah kehidupan nyata. Tujuannya adalah untuk mengembangkan keterampilan kritis, kreatif, komunikatif, dan kolaboratif siswa sesuai dengan kompetensi abad ke-21. Studi ini bertujuan untuk mengeksplorasi potensi dan tren yang dilaporkan dari implementasi STEAM dalam Kurikulum Independen dalam pembelajaran biologi di Indonesia, khususnya di daerah yang kurang berkembang, daripada untuk menentukan efektivitas langsungnya. Tinjauan Pustaka Sistematis (SLR) dilakukan menggunakan Google Scholar untuk mengidentifikasi artikel-artikel relevan yang diterbitkan antara tahun 2018 dan 2024. Proses seleksi melibatkan penyaringan relevansi dengan pembelajaran berbasis STEAM dalam biologi dan penerapan kriteria inklusi seperti fokus pada pendidikan SMA dan konteks Indonesia. Dari 10 artikel terpilih, analisis dilakukan menggunakan sintesis tematik untuk mengidentifikasi pola dan tren umum. Hasil menunjukkan bahwa Kurikulum Independen memiliki potensi untuk mendukung pembelajaran berbasis STEAM, bahkan di daerah yang kurang beruntung, dan integrasi ini dapat mendorong pengembangan kompetensi siswa sesuai dengan tujuan pembelajaran abad ke-21.*

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A. Introduction

21st-century skills, such as critical thinking, creativity, collaboration, and communication, are essential in biology learning, as they can be effectively developed through STEAM-based approaches that engage students in real-world problem-solving activities because they can ensure that students have the skills to learn and innovate, become users of information technology, work actively, and survive by using life skills (Andrian & Rusman, 2019). In line with the opinion of St. Louis et al. (2021) 21st century skills are the development of skills that are prioritized in involving creativity, innovation, critical thinking, problem solving, decision making, learning, communication, collaboration is important in developing skills that link information technology to the future readiness of children when working in the field. The importance of these 21st century moral skills is applied in learning in schools. 21st century learning is an implication of developments from time to time by society from primitive to agrarian, industrial, and towards an informative society which is marked by the development of digitalization (Rahayu et al., 2022).

One of the sciences that continues to develop in the 21st century is Biology. Biology is a science that studies living things and their lives. Biology material not only studies concrete materials that exist in nature, but also studies abstract materials in it such as chemical processes that occur in the body, hormonal systems, and coordination systems (Sudarisman, 2015). Thus, biology requires high-level thinking skills such as critical, logical, and analytical thinking so that in its implementation various supporting tools are needed such as the use of learning media and laboratory facilities. Modern science education must offer a rich context for developing various 21st-century skills, such as critical thinking skills, skills in problem-solving processes, information literacy, and various other science practices.

Hadinugrahaningsih et al. (2017) opinion STEAM is a 21st century learning approach that aims to develop children's soft skills that link the fields of science, developing technology, engineering, art, and mathematics that are developed holistically through 21st century learning experiences. STEAM learning is contextual learning, where children are invited to understand events that occur in the scope of life so that children are able to explore all their abilities and produce different works from individuals and groups. Collaboration, cooperation, and communication are applied in the learning process because STEAM is carried out in groups to stimulate the ability to be responsible and solve problems both personal and interpersonal towards learning and are able to construct an understanding of the material presented by the teacher (Duban et al., 2017; Y. Lee, 2021).

Mapping the potential of STEAM in the Merdeka Curriculum is essential, as existing studies on STEAM either focus on previous curricula or international contexts, and there is a lack of systematic evidence regarding its implementation in Indonesian senior high school biology, particularly in underdeveloped areas because this learning is one of the cooperative learning which is part of constructivism learning. This is in accordance with the Merdeka curriculum learning where students learn and innovate to utilize technology as a tool to inspire and empower students actively, and build their own knowledge and understanding through projects. The projects given in learning with the STEAM approach require students to be able to understand biology as a science, utilize developing technologies such as computing to help find concepts through inquiry, then present them by paying attention to ethics and aesthetics as art and displaying forms of biological material (Coates, 2020).

Here are some previous studies that support researchers in using STEAM in biology research. First, an article written by Retnowati et al. (2021) states that biology learning with environmental change material integrated with STEAM-based entrepreneurship can improve students' critical thinking skills and interest in entrepreneurship in the Merdeka Curriculum. In addition, Patresia's research states that STEAM-based worksheets can strengthen students' knowledge of process skills. The difference between this study and previous studies lies in the material being studied. Previous studies related to entrepreneurial interest, while this study only focuses on the potential of STEAM in the 2013 Curriculum in biology studies. However, both prove that STEAM has the potential to be applied in the Indonesian Curriculum.

In addition, the latest research conducted by Pudjiastuti et al. (2024) conducted a study on the potential and form of STEAM implementation in Biology learning, especially in learning models, teaching materials and learning materials in high schools that can be applied at SMA Sint Louis Semarang. The results showed that STEAM has the potential to be applied to learning in the form of PjBL and PBL learning models, teaching materials in the form of Modules or LKPD, as well as in several learning materials, namely biotechnology, environmental pollution, coordination systems, viruses, fungi and the environment and sub-materials on recycling plastic waste with the Independent Curriculum. Meanwhile, the research conducted by Farwati et al. (2021) stated that the implementation of STEAM is used as a strategy, an approach that is integrated with other learning models and developed into teaching materials, modules and learning media, so it can be concluded that STEAM is very suitable for application to the Independent Curriculum.

This is the reason the author conducted a literature study on the potential for implementing STEAM in the Independent Curriculum. This study is novel in systematically reviewing the potential implementation of STEAM specifically in senior high

school biology within the Merdeka Curriculum, with a focus on underdeveloped regions, which has not been explicitly addressed in previous literature. This is done to find out whether disadvantaged areas have the potential to implement STEAM in the Independent Curriculum.

B. Material and Method

This study was conducted as a Systematic Literature Review (SLR), following internationally recognized standards such as the PRISMA guidelines, to ensure a transparent and rigorous selection, screening, and synthesis of relevant articles. This is done by reviewing and analyzing the results of research that has been carried out previously. The data collected comes from a database for the last eight years (2018-2024). A total of 90 articles were initially identified through keyword searches. After screening titles and abstracts for relevance and applying inclusion and exclusion criteria, 25 articles were selected for full-text review, and finally, 10 articles were included in the systematic analysis. Articles were selected based on the following inclusion criteria: (1) published between 2018 and 2024, (2) focused on STEAM-based learning in senior high school biology, and (3) published in peer-reviewed journals or reputable conference proceedings. Articles that did not meet these criteria, such as those outside the educational or biology context, were excluded. The systematic literature review includes three stages according to Wahono (2015): planning, implementation, and reporting (see Figure 1).

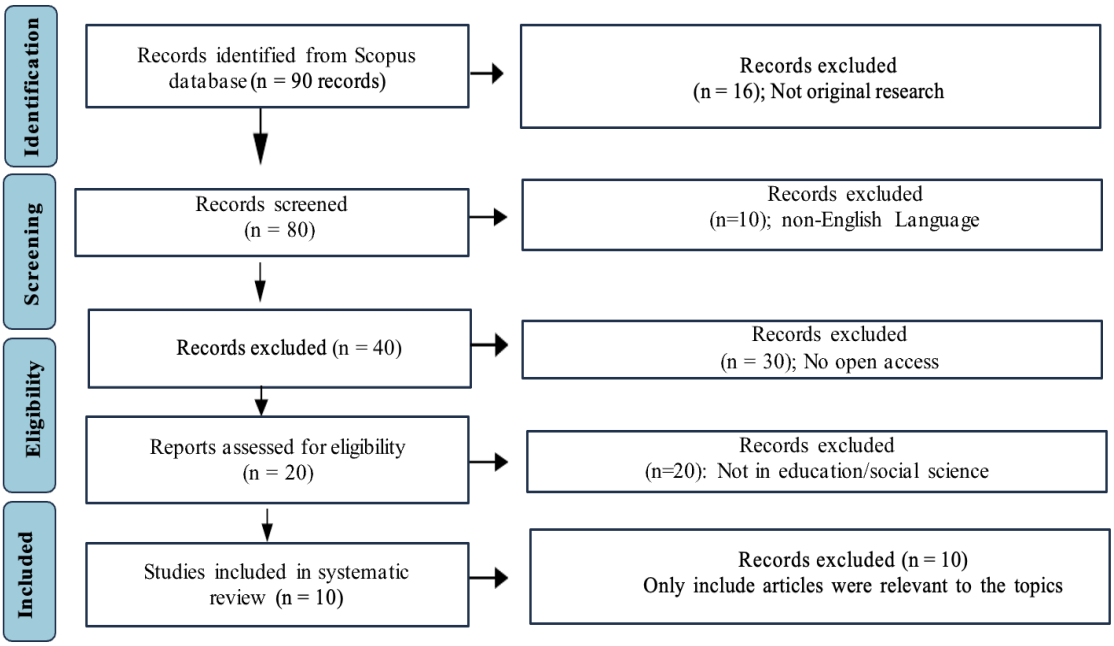

Figure 1 PRISMA flow diagram of study selection

1. Planning

This stage includes the preparation of a systematic literature review protocol. This study uses Publish or Perish to determine the research topic from the journal found.

2.Conducting

This stage is the implementation of systematic literature review. This stage begins with searching for articles based on the criteria that have been set in the planning stage. The next step is the selection of articles. The selected articles are articles that are in accordance with the research topic. Based on the results of the article search, 10 articles were selected. After selecting the articles, the next step is to synthesize the data with the aim of analyzing and evaluating various research results from various literatures. The data synthesis carried out in this study is in narrative form.

3. Reporting

The reporting stage is the final stage in systematic literature review research. This stage includes writing the results of the systematic literature review in written form according to the specified format.

C. Results and discussion

A total of 90 publications were initially identified through keyword searches, of which 10 articles met the inclusion criteria and were analyzed in depth. The analysis was conducted using the Publish or Perish 8 software database, specifically focusing on Scopus journals. The selected keywords were utilized to gather a comprehensive. The article selection process using in SLR using the PRISMA model can be seen in Figure 1, and the findings are presented in Table 1, showing an overview of research studies.

Table 1 Analyze the potential for implementing STEAM in the Merdeka Curriculum

No.	Author's	Title and year	Type of STEAM integration	Results
1	Prabawati et al. (2023)	Science Learning with Ethno-STEAM Content as an Effort to Empower Creative Thinking Skills of Independent Curriculum Students (2023)	Ethno-STEAM, Project-Based	The Ethnoscience and STEAM approaches complement each other effectively in learning to improve 4C skills in the independent curriculum. In addition, the Ethnoscience and STEAM learning designs are designed and applied through learning tools, and it is proven that ethno-STEM project-based learning can increase the average critical and creative thinking skills of students.
2	Wandraini (2022)	Implementation of STEAM (Science, Technology, Engineering, Arts, and Mathematics) in Biology Learning (2022)	Integrated STEAM	According to the article analysis, teachers and students will and have implemented STEAM in biology learning. Teachers and students both benefit from incorporating STEAM into biology learning, which also improves students' biology learning abilities.
3	Rohmah (2023)	Implementation of the Independent Curriculum Reviewed from the Potential of STEAM in Ecosystem Material at SMA PGRI 2 Kayen Pati (2023)	STEAM-based Curriculum Implementation	The results of this study indicate that SMA PGRI 2 Kayen Pati has implemented an independent curriculum based on the STEAM approach in learning biology on ecosystem material.
4	Umami (2023)	The Effectiveness of Learning Through Steam in the Independent Curriculum at SDN Palebon 01 Semarang (2023)	STEAM Problem-Solving	The STEAM learning model is quite effective in improving the science learning outcomes of grade IV in the independent curriculum on the material on changes in matter.
5	Motimona and Maryatun (2022	Implementation of the STEAM Learning Method in the Independent Curriculum for PAUD (2023)	STEAM Problem-Solving	The results of this study indicate that with the STEAM approach, children will develop science and technology-based ideas by engaging in problem-solving activities originating from five interrelated disciplines. The implication of this study is to increase teachers' knowledge about the steps of implementing the STEAM method in the independent curriculum. Keywords: steam learning; independent curriculum for pre-school; early childhood
6	Zulfatun (2023)	Implementation of STEAM-Based Science Learning on Building a Civilized Society Material for Grade 4 in the Independent Curriculum at SDN 4 KLAMBU (2023)	STEAM Problem-Solving	The results of the study showed that the implementation of STEAM-based science learning on the material Building a Civilized Society for grade 4 at SDN 4 Klambu has been running very well. Gurun implements STEAM-based science learning by utilizing the environment around students. Through STEAM learning, students find it easier to understand the material because they are directly involved in the learning process.
7	Damayanti et al. (2023)	Analysis of the Potential of STEAM Application in Tissue Culture Learning in the Independent Curriculum for High Schools	STEAM Literature Analysis	Based on literature reviews from several journals, it can be seen that STEAM with the implementation of their curriculum can have the potential to be applied in biology learning, especially tissue culture learning. The STEAM method has a collaborative learning nature which, when applied to tissue culture lessons, will be more relevant, whose activities involve more practical activities.

No.	Author's	Title and year	Type of STEAM integration	Results
8	Khoirrunnisa and Isdaryanti (2024)	The Effectiveness of STEAM-Based Learning (Science, Technology, Engineering, Art, and Mathematics) to Improve Science Learning Outcomes in Grade V Students of Srondol Wetan 06 Elementary School (2024)	STEAM Experimental	Based on the results of research that has been conducted, STEAM-based learning is effective in improving student learning outcomes
9	Mabsutsah and Yushardi (2022)	Teacher Needs Analysis for STEAM-Based E-Modules and Curriculum Freedom on Global Warming Material (2022)	STEAM E-Module	On average, teachers agree with the development of STEAM-based e-modules and independent curriculum to improve students' learning outcomes and science process skills.
10	Priyono et al. (2024)	The Potential of Implementing Science, Technology, Engineering, Art and Mathematics (STEAM) in Science Learning on Climate Change Material Reviewed from the Perspective of Science Teachers in Demak Regency. (2024)	STEAM E-Module	Implementation of STEAM requires more implementation, development of relevant learning materials, and ongoing support from various parties in the form of costs so that it can improve the quality of science learning and students' environmental awareness in the future.

Across multiple studies, STEAM-based learning consistently shows positive pedagogical outcomes in science and biology education. Several studies reported improvements in students' critical thinking, creativity, engagement, and academic achievement when interdisciplinary STEAM projects were implemented. For example, ethnoscience-integrated STEAM activities were found to enhance 21st-century skills while strengthening connections between local knowledge and scientific concepts (Prabawati et al., 2023). Similar findings were reported in biology and science classrooms, where STEAM approaches increased student motivation and learning outcomes (Wandraini, 2022; Umami et al., 2023; Motimona & Maryatun, 2023; Nikmah et al., 2023). These results indicate that STEAM can support deeper conceptual understanding and contextual learning across different educational levels.

Several studies also highlight the compatibility between STEAM pedagogy and the Independent Curriculum framework, which emphasizes project-based, interdisciplinary, and student-centered learning promoted by Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi. Classroom implementations in topics such as ecosystems and tissue culture demonstrate that STEAM can be integrated into biology instruction through collaborative projects and inquiry-based activities (Rohmah & Roshayanti, 2023; Damayanti et al., 2023). The development of STEAM-based e-modules further supports curriculum implementation by improving science process skills and learning outcomes (Mabsutsah & Yushardi, 2022).

Despite these positive findings, several studies emphasize challenges in implementing STEAM effectively. Limited instructional materials, inadequate facilities, funding constraints, and varying teacher readiness were identified as major barriers to sustainable implementation (Priyono et al., 2024). These challenges are particularly relevant in underdeveloped or resource-limited regions, where contextual adaptation and institutional support are essential.

In conclusion, the reviewed studies demonstrate that the STEAM approach has strong potential to support the Merdeka Curriculum, particularly in fostering higher-order thinking skills and promoting learning that is more contextual, collaborative, and meaningful. Nevertheless, effective implementation requires consistent support in the form of educational policy, teacher training, and the development of relevant learning resources

The results of the analysis show that STEAM has the potential to be applied to the independent curriculum because it can help students develop the skills and abilities needed in the future. Here are some reasons why STEAM has the potential to be applied to the Independent Curriculum:

Collaborative learning

STEAM emphasizes collaborative learning, so the classroom is designed flexibly to create a fun and interactive learning atmosphere. The STEAM learning system emphasizes integrated and integrated methods; students can work together in a team to find solutions to problems found. It also helps them learn to collaborate with others. So that cooperation is created in a team.

Based on data from the Ministry of Education and Culture, Ristek, more than 97% (see Figure 2) of teachers agreed and strongly agreed that the Independent Curriculum provides flexibility to design

learning according to student and school conditions (Ministry of Education and Culture, 2024)

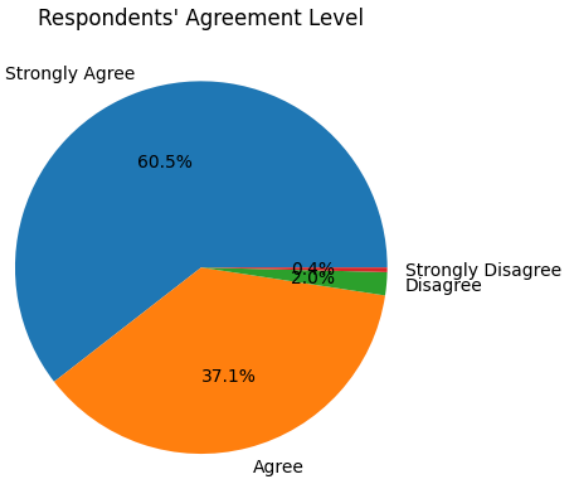

Figure 2
Survey results in 164 Schools in Indonesia.
(Source: Additional Survey in AN Module 2023: n=164 thousand educational units)

This makes it easier for teachers to design learning plans that are appropriate to the situation and conditions of students, so that appropriate learning is created. This suitability is one of the factors in creating collaborative learning.

Facilitating integrated learning

Art in STEAM can facilitate transdisciplinary integrated learning that provides deeper understanding. Some of the factors;

1) STEAM combines science, technology, engineering, art, and mathematics into one learning approach.
2) Arts practices in STEAM can encourage independent learning, social responsibility, and creative problem solving.
3) STEAM can help students develop the skills and abilities they will need in the future.
4) STEAM can stimulate children's critical thinking, communication, creativity, and collaboration skills.
5) STEAM can be a strong foundation for children to build an attitude of liking mathematics and science.

Building a positive attitude towards various fields of science

STEAM provides an opportunity for children to develop positive attitudes towards various fields of knowledge, such as science and mathematics. STEAM learning is a very important method to apply in the teaching and learning process because it has many advantages. Such as preparing the next generation who are ready to face the development of the times, helping to develop innovations in life to improve the quality of students. STEAM learning is important because art practices in STEAM can encourage independent learning, social responsibility, and creative problem solving (Rolling, 2016). Art in STEAM can also facilitate integrated transdisciplinary learning that provides deeper understanding (Liao, 2016).

Motivating students to learn and think critically

STEAM motivates students to learn to explore their own skills. The STEAM method emphasizes a form of learning that focuses on the process, later students are able to understand and find solutions related to the problems they want to solve. In the process, science will be applied in real situations, this helps students develop skills such as creativity to critical thinking skills.

Helping students solve problems creatively

STEAM helps students get used to solving problems with creative abilities and ways. STEAM also makes learning more relevant to life, helping students build self-concept actively. And improve student literacy through STEAM, in accordance with the objectives of this system. So that students' understanding and knowledge through STEAM can increase and can be used to solve problems.

For example, students will be helped and encouraged to find systematic and repeatable ways to design objects, processes and systems that meet the needs of human life. Elements in STEAM can start from a problem, desire or need with a measurable level of criteria after which testing of problem identification or constraints is carried out.

According to the Ministry of Education and Culture, schools in disadvantaged areas are still able to implement the Independent Curriculum to improve students' literacy and numeracy scores. This shows that the Independent Curriculum can benefit schools in various contexts. The following is a graph showing that there has been an increase in literacy and numeracy scores in disadvantaged areas.

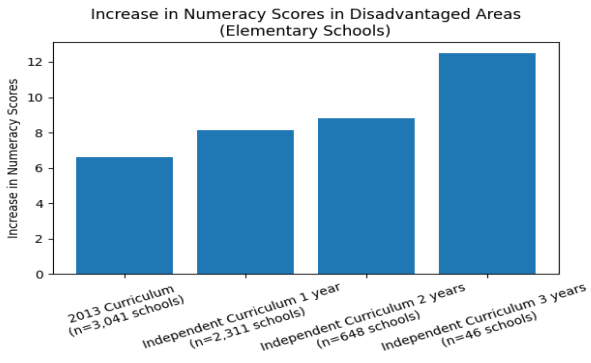

Figure 3
Increase in Numeracy scores in disadvantaged areas
(Source: Ministry of Education and Culture 2024)

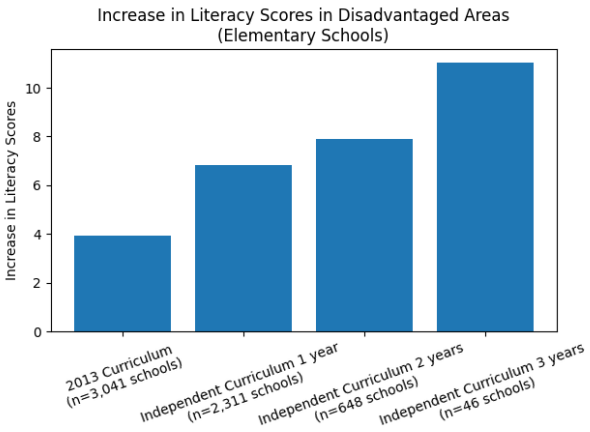

Figure 4
Increase in literacy scores in underdeveloped areas
(Source: Ministry of Education and Culture 2024)

From the Figure 3 and Figure 4, it is stated that the implementation of the Independent Curriculum in underdeveloped areas can be applied, this is also in line with research conducted by Lase (2023) regarding the Implementation of the Independent Curriculum in 3-T Regions. The results of the study showed that the implementation of the Independent Curriculum in elementary schools in 3-T areas has been going quite well. This can be seen from the teacher's planning in compiling learning tools such as teaching modules and learning objective flows (ATP), the use of various learning methods such as discussions, questions and answers, lectures, and quizzes. Project Based Learning (PjBL) methods, Problem Based Learning (PBL) and the use of various learning media such as visuals, audio, and printed materials such as books to increase the effectiveness of learning and adjust to the needs and conditions of students. To measure learning achievement, teachers carry out formative and summative assessments in learning. The Independent Curriculum has succeeded in increasing students' interest in learning and teachers' creativity, creating more interactive and enjoyable learning. However, there are still obstacles such as limited facilities, weak internet access, and lack of teaching materials. Teachers in 3-T areas have shown significant adaptation using conventional methods, local languages, and materials without internet connection, as well as overcoming obstacles with initiatives such as online training and collaboration between teachers.

Based on the findings of the reviewed studies, there is preliminary and conditional evidence suggesting that STEAM integration within the Independent Curriculum may also be feasible in underdeveloped regions. In this study, underdeveloped regions refer to those classified under Presidential Regulation No. 63 of 2020 on the Determination of Underdeveloped Regions for 2020–2024. These regions are identified using six criteria: community economic conditions, human resources, facilities and infrastructure, regional financial capacity, accessibility, and regional characteristics. According to this regulation, 62 districts are categorized as underdeveloped, including Nias (North Sumatra), Mentawai Islands (West Sumatra), North Musi Rawas (South Sumatra), North Lombok (West Nusa Tenggara), Central Sumba and Alor (East Nusa Tenggara), Donggala (Central Sulawesi), Pulau Taliabu (North Maluku), Nabire and Asmat (Papua), and Teluk Wondama and Pegunungan Arfak (West Papua). This policy context provides a framework for interpreting the findings; however, further empirical research is needed to evaluate STEAM implementation specifically within these regions

The classification of underdeveloped regions based on the six criteria indicates that the implementation of the Independent Curriculum and the STEAM approach in 3-T areas requires contextual and adaptive learning strategies that consider social, economic, and infrastructure limitations. The implications of this study for education are the need to develop STEAM-based instructional materials that are simple, locally relevant, and usable without heavy reliance on advanced technology. For teachers, these findings can serve as a reference for designing teaching modules, project-based activities, and flexible assessments that align with the conditions of schools in underdeveloped regions. Meanwhile, for policymakers and stakeholders, the results highlight the importance of improving teacher training, providing contextual teaching resources, and ensuring equitable access to facilities and internet connectivity so that the implementation of the Independent Curriculum integrated with STEAM can be carried out effectively and sustainably in 3-T areas.

D. Conclusion

The review indicates that the Independent Curriculum in senior high school biology demonstrates conditional potential for STEAM integration. In underdeveloped regions, successful implementation is likely to depend on contextual factors such as infrastructure readiness, teacher preparedness, and the availability of learning resources. However, this study has several limitations. First, the number of reviewed articles was relatively small, which restricts the generalizability of the findings. Second, many studies were concentrated in particular regions, creating potential regional bias. Third, only a limited number of empirical studies specifically examined STEAM implementation in biology learning contexts, indicating a gap in subject-specific evidence. Future research should therefore focus on conducting larger-scale empirical and experimental studies across diverse regions, particularly in 3-T areas, to examine the effectiveness of STEAM-based biology instruction. Further studies are also recommended to develop context-sensitive teaching materials, evaluate long-term learning

outcomes, and investigate teacher readiness and professional development needs to support sustainable STEAM implementation within the Independent Curriculum.

E. Acknowledgement

The researcher would like to thank all parties who have helped in the research process entitled Analysis of Potential Implementation of STEAM (Science, Technology, Engineering, Art, Mathematics) in the Merdeka Curriculum for Senior High School Biology. This article is a written work for the results of the SLR research using a quantitative approach to make it easier for other researchers to find a big picture of the research to be studied.

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