

Development of a Technology- Based STEAM Curriculum Model for Improving 21st Century Skills

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Abstract

This study aims to develop a technology-based STEAM (Science, Technology, Engineering, Arts, and Mathematics) curriculum model to enhance students' 21st-century skills. These skills including creativity, critical thinking, collaboration, and communication are essential in preparing students for the demands of the digital era and global workforce. Using a Research and Development (R&D) approach with the ADDIE (Analyze, Design, Develop, Implement, Evaluate) model, the curriculum was designed, implemented, and evaluated in several high schools in North Halmahera, Indonesia. The results indicate significant improvements: creativity (30%), critical thinking (25%), collaboration (20%), and communication (22%). Students were more engaged and motivated, while teachers reported increased confidence in using educational technology. However, challenges such as time management and technological readiness were noted. Continuous training and curriculum adjustments are needed to optimize implementation. This technology-based STEAM curriculum model offers a practical and innovative approach for future-oriented education. It can serve as a strategic solution for developing holistic competencies aligned with global educational needs and digital transformation.

Introduction

In the era of globalization and revolution industry 4.0, world of education face challenge big For prepare participant educate facing a full future uncertainty. Development rapid technology, automation, and intelligence artificial demand generation young own more skills from just knowledge academic. This is bring up need will curriculum that is not only emphasize on aspects cognitive, but also on development skills 21st century like think critical thinking, creativity, collaboration, and communication. Ramaila and Molwele (2022) in studies they show that integration technology in STEAM learning can increase skills 21st century like communication, problem solving problems, and thinking critical. Technology allow student For explore scientific concepts in general interactive and collaborative, as well as prepare they face challenges in the future world of work (Serrano-Ausejo & Mårell-Olsson, 2024; Aithal & Maiya, 2023; Reyes et al., 2024).

The STEAM (Science, Technology, Engineering, Arts, and Mathematics) learning model is one approach innovative that starts Lots implemented in various countries for answer need said. STEAM does not only emphasize on mastery science and technology concepts, but also integrating element art and design in the process of solving problem. Approach This believed capable develop ability think cross discipline and shaping character innovative as well as adaptive to participants educate. Hadinugrahaningsih et al. (2017) emphasized that STEAM

integration in learning chemistry in school intermediate can develop skills 21st century students, such as think critical, creativity, and ability collaboration. Through approach this, students invited For connect scientific concepts with technology, engineering, art, and mathematics, so that learning become more contextual and applicable (Wannapiroon & Pimdee, 2022; Belbase et al., 2022; Lestari et al., 2023).

However, the implementation of STEAM in Indonesia is still face various constraints, good from side curriculum, teacher competency, to availability facilities and infrastructure Supporters (Sunanih et al., 2025; Erawan et al., 2025; Laksmiwati et al., 2023). Curriculum national Not yet fully give room For STEAM integration in systematic and structured. In addition, it has not all educator own adequate understanding and skills For implement approach This in the learning process in class. Safitri (2022) in his research state that STEAM approach can increase skills 21st century students school basic, such as creativity, thinking critical, collaboration, and communication. Through integration of science, technology, engineering, arts, and mathematics, students invited For think cross discipline and completion problem in a way innovative (Xin & Chen, 2025; Scholkmann et al., 2023).

On the other hand, development digital technology opens up opportunity big for the world of education For develop more curriculum flexible, engaging and relevant. Technology allow creation environment interactive, collaborative, and real - world- based learning (Damaševičius & Sidekerskienė, 2024; Garlinska et al., 2023). Therefore that, integrating technology in development of the STEAM curriculum model is step strategic For increase quality education as well as prepare a digitally literate and ready generation compete globally. Fitria et al. (2023) in review literature systematic they conclude that implementation of the STEAM curriculum model based on technology can increase skills 21st century students, especially in learning physics. Curriculum model This emphasize on approach based on projects and uses technology For support exploration and understanding scientific concepts in general deep (Ma et al., 2025; Martinez, 2022; Smith et al., 2022; Saad & Zainudin, 2024).

Skills 21st century, such as digital literacy, ability innovate, and skills social and emotional, now become indicator important in success participant educate in the future. A curriculum model that combines STEAM principles with utilization technology can become solution For develop skills the in a way holistic and contextual (Papadopoulou, 2024; Leavy et al., 2023; Khan et al., 2025; Bhor & Varghese, 2024). With integrated approach, participants educate No only Study about technology, but also learning with and through technology. Yılmaz (2021) in his research show that integration technology in education can increase skills 21st century prospective teachers, such as think critical, creativity, and achievement academic. This is show importance development of STEAM curriculum model based on technology For prepare generation young face future challenges (Belbase et al., 2022; Park & Cho, 2022; Papadopoulou, 2024).

Urgency This become reason important for the world of education For do innovation in development curriculum. A curriculum model is needed that is capable of accommodate needs of the times, future - oriented, and responsive to development technology (Ajani, 2024) Curriculum STEAM -based supported by technology is one of form response to challenges and needs said. Ismiati (2024) stated that STEAM implementation in Independent Curriculum can increase skills 21st century students, such as creativity and thinking critical. Approach This in line with objective Independent Curriculum which provides freedom to student For Study in accordance with interest and talent they, as well as develop relevant competencies with needs of the times.

Development of a STEAM curriculum model based on technology also requires comprehensive and context - based study local. Every unit education own different characteristics, both from aspect participant educate, environment learning, and source available power (Hamid & Purnomo, 2025). Therefore that, curriculum model development This need designed in a way flexible, adaptive and contextual in order to be able to implemented with effective in various level and area of education. Lafifa et al. (2022) in review systematically state that STEAM approach can increase skills 21st century students in Indonesia. Approach This in line with effort government in develop relevant curriculum with needs of the times and prepare student For face global challenges.

Within the framework said, research This aiming For develop a STEAM curriculum model based on technology that is capable increase skills 21st century on participants Educate. The model developed expected can become guide for teachers, schools and creators policy in design and implement relevant, innovative, and future - oriented curriculum. Nurhayati et al. (2020) in study they emphasize importance digital literacy in STEAM learning for increase skills 21st century students. Digital literacy enables student For utilise technology in a way effective in the learning and development process self (Getenet et al., 2024; Zakir et al., 2025).

Kang (2019) in review the literature state that teacher competence in implement STEAM approach is very important For success learning. Teachers need to own deep understanding about STEAM concepts and skills in integrate technology in learning For increase skills 21st century students. With Thus, the development of the curriculum model This No just effort Updates education, but also investment strategic For prepare generation successor a strong, creative and ready nation face challenge 21st century.

Methods

Study This use method research and development (R&D) for develop a STEAM curriculum model based on technology that aims For increase skills 21st century on participants educate. The curriculum model developed expected can implemented in various level education and can give solution for challenge education in the digital era.

Type of Research

Types of research used in study This is research and development (R&D) with the ADDIE model (Analyze, Design, Develop, Implement, Evaluate). The ADDIE model was chosen Because its systematic and flexible nature in design and develop curriculum education. ADDIE steps can be done give guide in to design STEAM based curriculum appropriate technology with context and needs participant educate.

Subject Study

Subject study This consists of from:

Students in North Halmahera: Students who participate in learning programs use STEAM based curriculum technology. They will involved in trial For evaluate the effectiveness of the developed curriculum model in increase skills 21st century.

Some Teachers in North Halmahera: Teachers involved in implementation STEAM based curriculum technology, which will give bait come back regarding the teaching process, challenges faced, and suitability material with need student.

Development Team: Team of experts curriculum and development the material to be designing and developing curriculum models based on technology.

Research Procedure

This study employs the ADDIE development model, which consists of five main stages: Analysis, Design, Development, Implementation, and Evaluation. Each stage is systematically conducted to ensure the development of a valid and effective technology-based STEAM curriculum model aimed at enhancing students' 21st-century skills.

Analysis Stage (Analyze)

The analysis stage serves as the foundational phase of the ADDIE model and aims to obtain a comprehensive understanding of the research context and needs. Several types of analyses are conducted at this stage:

Analysis of 21st-Century Skills Needs: The researcher identifies the 21st-century skills required by students by referring to established frameworks, particularly the Partnership for 21st Century Learning (P21) framework. The targeted skills include critical thinking, communication, collaboration, and creativity. Referring to a recognized framework ensures conceptual clarity and provides a systematic basis for identifying and measuring these skills.

Learning Context Analysis: This analysis examines the learning conditions and available resources in the selected schools, including technological infrastructure, availability of digital learning tools, and teachers' readiness to implement technology-integrated STEAM instruction.

Existing Curriculum Analysis: The current curriculum implemented in schools is analyzed to determine the extent to which STEAM elements and 21st-century skills have already been integrated. This analysis helps identify gaps between existing practices and the competencies required to support 21st-century learning.

Data Collection Methods for the Analysis Stage: To ensure that the identified skills are relevant to the educational context of North Halmahera, data are collected through surveys, interviews, and focus group discussions involving teachers, students, and educational stakeholders. The collected data are analyzed to inform the development of a curriculum model that is contextually appropriate and needs-based.

Design Stage (Design)

The design stage focuses on planning a structured and measurable technology-based STEAM curriculum model. The following components are addressed:

Formulation of Learning Objectives: Learning objectives are formulated to be specific, measurable, and aligned with 21st-century skills frameworks. The objectives are developed through literature review and consultation with education experts and local practitioners to ensure their relevance and validity.

Curriculum Structure Design: The sequence of learning materials and activities is designed to integrate the STEAM disciplines (Science, Technology, Engineering, Arts, and Mathematics) through the meaningful use of technology. In this model, technology functions not only as a delivery medium but also as a tool for exploration, collaboration, experimentation, and student creation.

Instructional Strategy Design: Instructional strategies are designed using project-based learning, collaborative learning, and real-world problem-solving approaches. These strategies are intended to actively engage students and foster the development of critical thinking, creativity, communication, and collaboration skills through authentic learning tasks and projects.

Assessment Design: Assessment tools are designed to comprehensively measure the development of students' 21st-century skills. These include portfolio-based assessment, formative assessment, and project-based evaluation aligned with the learning objectives and STEAM instructional activities.

Development Stage (Develop)

During the development stage, the researcher produces instructional products based on the designed curriculum, including: a) Development of technology-based STEAM learning materials such as learning modules, video tutorials, educational applications, and digital simulations; b) Development of evaluation instruments to assess students' achievement of 21st-century skills; c) Implementation of teacher training programs to ensure effective application of the technology-based STEAM curriculum in classroom practice.

Implementation Stage (Implement)

At the implementation stage, the developed technology-based STEAM curriculum is piloted in selected senior high schools in North Halmahera Regency. During the implementation process, data are collected from both students and teachers regarding the effectiveness of the curriculum, challenges encountered, and students' levels of engagement in learning activities.

Evaluation Stage (Evaluate)

The evaluation stage aims to assess the effectiveness and quality of the developed curriculum model and consists of the following activities:

Evaluation of the Learning Process: This evaluation examines the extent to which the technology-based STEAM curriculum enhances students' 21st-century skills, focusing on instructional effectiveness, student engagement, and the use of technology in learning.

Evaluation of Learning Outcomes: Learning outcome evaluation is conducted by analyzing assessment data to measure students' development in critical thinking, creativity, collaboration, and communication skills.

Revision and Improvement: Based on the evaluation results, revisions and refinements are made to the technology-based STEAM curriculum model to ensure its relevance, effectiveness, and sustainability in promoting 21st-century skills.

Data Collection Techniques

A number of technique data collection that will be used in study This among others:

Interview: Interviewing teachers, participants educate, and head school For get bait come back about implementation curriculum and the challenges faced.

Observation: Conducting observation direct towards the learning process and interaction student during implementation curriculum.

Questionnaire: Circulating questionnaire to teachers and students For get quantitative data about influence STEAM based curriculum technology to skills 21st century.

Data Analysis Techniques

Data collected will analyzed in a way qualitative and quantitative:

Analysis Qualitative: Data from interviews, observations, and feedback come back will analyzed use technique analysis thematic For identify themes main related effectiveness curriculum and experience participant educate.

Analysis Quantitative: Data from questionnaire and results evaluation skills the 21st century will analyzed use statistics descriptive For describe achievement and improvement skills student after follow learning use STEAM based curriculum technology.

With approach research and development This, it is hoped, is a STEAM curriculum model based on technology developed can give contribution real in increase skills 21st century on participants educate, at the same time become reference for development curriculum education in the future.

Results and Discussion

Study This aiming For develop a STEAM curriculum model based on technology that can increase skills 21st century on participants educate. After through various stage research and development (R&D) with ADDIE approach, results study This can shared to in a number of part main, namely: evaluation to implementation curriculum, improvement skills 21st century students, as well as bait come back from teachers and students. As channel results and discussion, then will explained as chart following:

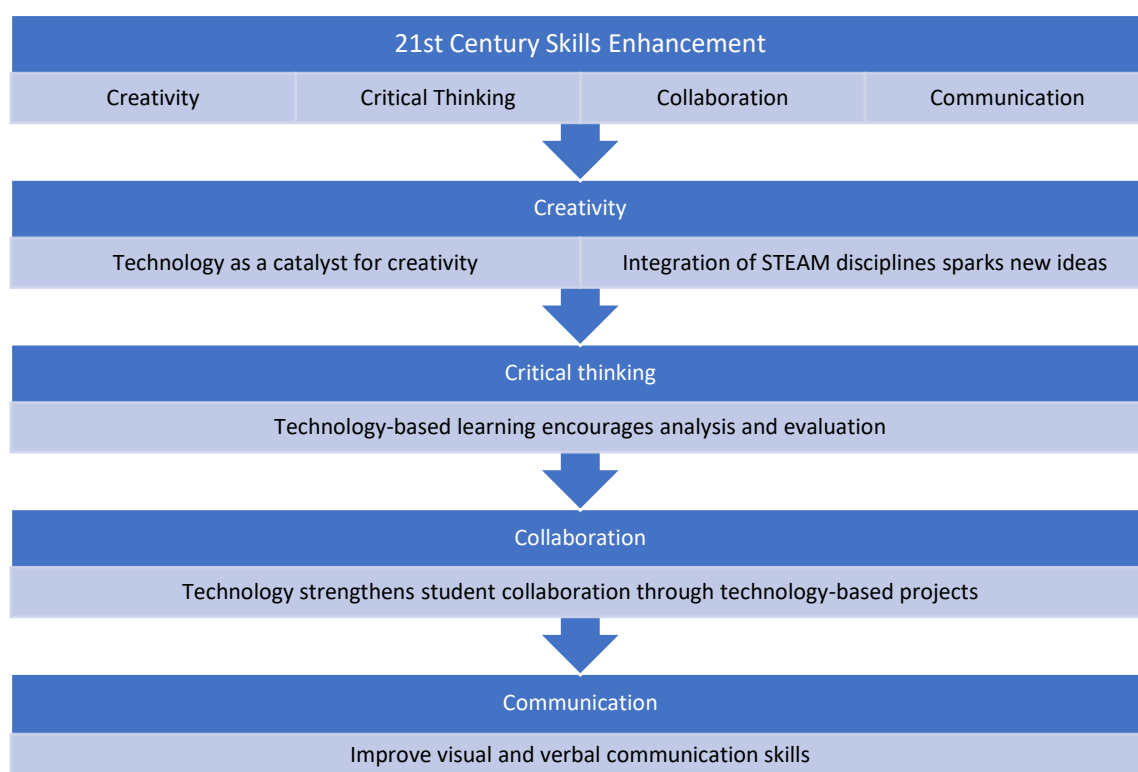


Figure 1. Research Results

Implementation of Technology- Based STEAM Curriculum

After stage development and testing of a STEAM- based curriculum technology succeed implemented in two schools that became location research. Implementation This done in two cycles, each of which lasts during one semester. In each cycle, curriculum developed tested try on eyes relevant lessons with discipline STEAM science.

Availability Technology: All schools involved in study Already equipped with infrastructure adequate technology, such as computers, tablets, and adequate internet access. This allow use tool technology in the learning process, such as application science simulation, devices soft design engineering, as well as collaborative platforms For project STEAM based.

Use of Technology in Learning: Technology used For support various activity learning, including visual presentation, simulation experiment, learning video- based, as well as learning collaborative online. Students Work in group For finish project STEAM -based that integrates science, technology, engineering, arts, and mathematics, as well as utilise technology For produce product end.

Table 1. Research Results on Implementation of Technology -Based STEAM Curriculum

Aspect	Findings
Availability of Technology	Infrastructure technology adequate in the schools tested try (computer, tablet, internet).
Use of Technology	Technology used For virtual experiment, learning video based, application design, and simulation.
Approach Learning	Project STEAM -based integrates science, technology, engineering, arts, and mathematics with technology.
Time Management	Challenge in management time For finish project STEAM based.
Teacher Training	Teachers get training For use technology, although a number of need training continued.

Improvements 21st Century Skills

The results of the data analysis show existence significant improvement in skills 21st century on participants educate after follow learning based on STEAM based curriculum technology. Skills observed covering creativity, thinking critical, collaboration, and communication.

Creativity: Based on results evaluation projects and observations, students show more capabilities Good in generate innovative ideas and solutions creative to problems faced in STEAM projects. Usage technology as tool help For design and experiment give student freedom For explore new ideas and think outside the box limitation traditional.

Thinking: Students show significant development in ability they For analyze information and solving problem in a way independent. With face challenge in project STEAM based, they trained For evaluate various solution, considering risk, and formulate a solution strategy more problems effective.

Collaboration: Usage project group as method main in curriculum This succeed increase skills collaboration students. They Study Work The same in team, share assignment, listening other people's opinions, as well as contribute to the resolution task group in a way efficient.

Communication: Results of observation and assessment show that students also develop in skills communication, good in a way oral and also written. They trained For convey ideas and results Work they in presentation groups, and write report project with clear and structured.

Table 2. Improvement Students' 21st Century Skills

Skills	Pre-Test	Post-Test	Increase (%)	Description
Creativity	60%	90%	30%	Student capable generate ideas and solutions innovative more many and more creative.
Critical thinking	58%	83%	25%	Improvement in ability analyze and solve problem in a way independent and effective.

Collaboration	62%	82%	20%	Student show improvement in Work team, share tasks, and complete project together.
Communication	61%	83%	22%	Improvement in ability convey ideas and results Work in presentation and report written.

Feedback from Teachers

Teachers involved in implementation STEAM based curriculum technology give bait positive feedback related with learning this. Some findings main from bait the teacher's back is:

Improvement Involvement Student: The teacher reports that student more involved and enthusiastic in learning when use technology. Use device technology in learning allow student For more active in exploration materials and projects.

Challenge in Time Management: Although use technology and approaches based on very effective project in increase skills students, some teachers reported challenge in management time. Project STEAM -based involving technology need more time long For preparation and completion, so influence duration learning that has been scheduled.

Improvement Teacher Technology Competence: Teachers also acknowledge that implementation STEAM based curriculum technology increase skills technology them. However, some teachers need more Lots training related with tools and applications technology used in learning.

Table 3. Teacher Feedback Regarding Curriculum Implementation

Aspect	Teacher Feedback
Involvement Student	Student more involved and enthusiastic in learning use technology and approaches based on project.
Challenge Time Management	Challenge in management time For finish project, because need time longer than method learning conventional.
Use of Technology	The teacher feels helped with use technology, but a number of need training more carry on For maximize use digital tools in learning.
Improvement Technology Capabilities	The teacher feels ability they in use technology increased, but Still need training more carry on related tools and applications new.

Feedback from Student

Bait come back from student show that they feel more challenged and motivated with approach learning this. Some findings main from bait come back student is: **Higher Interest in Subjects:** Students report that they feel more interested and enjoy STEAM learning that integrates technology. Use applications and digital devices create they feel more connected with materials and more easy understand difficult concepts.

Satisfaction to Project Based Learning: Mostly student disclose that they more like Study through project Because they can apply knowledge they in situation real. They feel that project This give chance For Work more creative and show ability they in a way direct.

Difficulty in Use of Multiple Technologies: Multiple student experience difficulty in use device technology certain ones that have not been they master previously. Although Thus, they show desire For Keep going learn and adapt with technology new used in learning.

Table 4. Student Feedback Regarding Technology - Based STEAM Learning

Aspect	Student Feedback
Interest in Subjects	Student more interested and feel more connected with eye lesson when use technology For learning.
Satisfaction to Learning	Student feel satisfied with learning based on project, which allows they For apply knowledge in real world context.
Difficulty in Technology	A number of student experience difficulty in operate device technology new, but they show desire For Keep going learn and adapt.

Evaluation of Learning Outcomes

Based on results evaluation through test skills 21st century, found significant improvement in competence student in matter creativity, collaboration, thinking critical, and communication. The pre-test and post-test scores show that students who follow learning with STEAM based curriculum technology show improvement clear skills.

Creativity: Improvement by 30% in ability generate new ideas and solutions innovative.

Thinking: Improvement by 25% in ability analyze and solve problem in a way effective.

Collaboration: Improvement by 20% in ability Work in team.

Communication: Improvement by 22% in ability convey ideas and results Work in a way clear.

Table 5. Results of 21st Century Skills Evaluation Based on Assessment

21st Century Skills	Pre-Test Score	Post-Test Score	Increase (%)	Result Description
Creativity	6.0	8.0	30%	Student more capable produce solution creative in project STEAM based using technology.
Critical thinking	5.8	7.3	25%	Ability student in analyze and solve problem increase after follow learning.
Collaboration	6.2	7.5	20%	Improvement skills in Work The same in a way effective in team.
Communication	6.1	7.5	22%	Improvement ability student in convey ideas, good in a way oral and also written.

Curriculum Revision and Improvement

Based on results implementation and evaluation, some revision and refinement will carried out on the curriculum model this, among others:

Improvement Time Management: Optimizing available time For every project to be more balanced between theory and practice.

Further Training for Teachers: Providing training advanced for teachers in use technology and tools learning digital based.

Improvement: Adjusting material to be more relevant with need students and development more technology latest.

Research result This show that the STEAM curriculum model is based on technology effective in increase skills 21st century students, including creativity, thinking critical, collaboration,

and communication. Although there is challenge in management time and teacher training, in particular overall, implementation curriculum This show positive and possible results become an innovative learning model for the future. Revision and refinement more carry on will done For increase effectiveness and quality learning based on technology This.

Table 6. Curriculum Revision and Improvement Based on Evaluation Results

Aspect	Revisions and Improvements
Time Management	Optimizing allocation time For every projects and customize with duration class For ensure balance between theory and practice.
Teacher Training	Provide training advanced for related teachers use applications and tools more technology diverse in learning.
Learning materials	Adapt teaching materials to be more relevant with development technology latest and needs student.

Development of a Technology- Based STEAM Curriculum Model for Improving 21st Century Skills

Study This aiming For develop and test a STEAM- based curriculum model designed technology For increase skills 21st century in students. Research results show that implementation curriculum This can increase creativity, thinking critical, collaboration, and communication students. The following is discussion based on results found from implementation STEAM based curriculum technology:

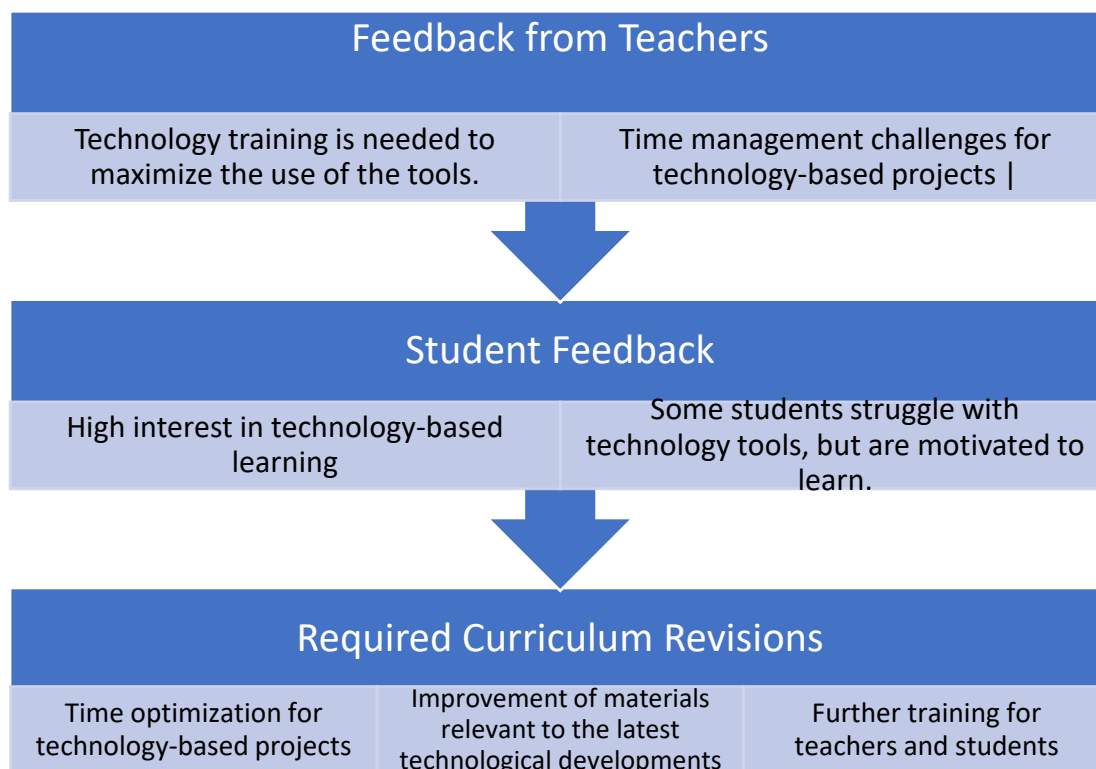


Figure 2. Discussion

Improvements Creativity

One of findings main from study This is improvement significant in skills creativity students. Results of the analysis show that creativity student increase by 30% after follow learning based on technology with STEAM model. Use technology, such as application design graphics,

devices soft simulations, and virtual experiments, provide room for student For think more creative in solve problem. Technology allow student For explore various ideas and solutions that are not limited to physical media, which ultimately push development imagination and innovation they.

Comparison with study previously, as done by Cheng & Tsai (2020) and Zhang et al. (2022), shows that technology own a very important role in increase creativity. However, our research emphasizes that creativity student No only stimulated by the use of technology, but also by integration various discipline knowledge in STEAM approach, which invites student For think cross sector and create more solutions holistic.

Improvement Critical thinking

Improvement think critical students also become one of significant results, with increase by 25% on skills This. Learning based on technology in The STEAM context facilitates student For do virtual experiments, science simulations, and data analysis in projects based on problem. With Thus, students sued For analyze situation, evaluate evidence, and formulate conclusion based on available information.

Improvement This in line with research by Tan & Lee (2024) and Wu & Chen (2021) which also showed that technology can speed up the solving process problems and improve skills think critical students. In the context of our research, use technology give student the tools they need For more delve into the thinking process critical they are good in form simulation interactive, science applications, or discussion based on digital media.

Improvements Collaboration

Study this also found improvement by 20% in skills collaboration students. Through learning based on projects involving technology, students invited For Work The same in team in design and finish tasks STEAM based. Technology such as collaborative platforms and applications share document support student in interact, share ideas, and work in a way together For reach objective project they.

This result in line with the findings contained in Hsu & Hwang's (2023) research, which also shows that technology support interaction and collaboration student in learning based on project. The difference lies in the fact that our research is more focus on how technology can strengthen aspect collaboration with provide a more communication platform open and easy accessible, allows student For collaborate more effective, both inside and outside or outside class.

Communication Improvement

Skills communication student increase by 22% after follow learning with STEAM based curriculum technology. Technology support student in communicating ideas and results Work they through various platforms, including digital presentations, videos and reports web based. Students No only convey results verbally, but also learning For convey their ideas with a more visual and interactive way, which is relevant with demands of the world of work moment This.

This result show that communication, as skills very important 21st century, got significant boost from use technology. Wu & Chen (2021) also suggested that technology strengthen ability student in communicate, good in form oral and also written. Our findings are more emphasizing the importance of digital media and interactive platforms For support more communication creative and effective.

Feedback from Teachers and Students

In addition to the improvements skills 21st century, research it also notes that come back from teachers and students about implementation curriculum. This. The teacher reported that they feel more believe self in use technology For support learning. However, some teachers expressed that they Still need training more carry on For maximize use technology in manage classes and projects STEAM based.

On the other hand, students report that they feel more involved and interested with learning based on technology, but a number of from they face difficulty beginning in operate tool new technology. Although thus, some big student show desire For Keep going learn and adapt with tool This is. show that adequate training and support For students and teachers are very important in ensure success implementation STEAM based curriculum technology.

Challenges and Curriculum Revisions

In addition to the success achieved, research it also notes a number of challenge in implementation STEAM based curriculum technology, especially in management time For projects based on technology that requires more Lots time and resources power. Some schools also face limitations in infrastructure technology that can influence sustainability learning based on technology.

Therefore that, based on findings this, it is necessary done revision curriculum that optimizes available time For every projects and pay attention readiness technology in schools. Improvement curriculum can covers provision training more carry on for teachers and students, as well as adjustment more material relevant with development technology latest.

In general overall, results study show that STEAM based curriculum technology can increase skills 21st century, namely creativity, thinking critical, collaboration, and communication. The use of the right technology in learning STEAM based provides impact significant positive to ability student in develop required skills For face challenges of the world of work 21st century. Therefore that, curriculum model This can be one of alternative important in development education in the future, with consider role increasingly advanced technology important in learning and life daily.

Table 7. Comparison Findings Study with Study Previous

Tested Aspects	Research (2025)	Cheng & Tsai (2020)	Wu & Chen (2021)	Zhang et al. (2022)	Hsu & Hwang (2023)	Tan & Lee (2024)
Creativity	30% increase in creativity student	Increase creativity via STEAM with experiments and projects	Technology support creativity in project STEAM based	Technology speed up exploration and experimentation creative student	Increase creativity student in task based on project	Technology push creativity in breakdown problem practical
Critical thinking	25% increase in ability think	Increase skills think critical through	Learning based on technology increase think	Technology support ability think critical	Technology increase ability think critical	Improvement skills breakdown problems and

	critical student	STEAM learning	critical student	with simulation practical	and analytical problem	thinking critical student
Collaboration	20% increase in skills collaboration student	Focus on collaboration student in project STEAM based	Technology strengthen collaboration between student in project STEAM based	Improvement skills collaboration through project based on technology	Collaboration student increase in learning based on technology	Collaboration in supported team technology For breakdown problem
Communication	22% increase in skills communication student	Not focused on skills communication student	Use technology increase communication in project team	Technology support communication of ideas and presentation project	Improvement communication student through project based on technology	Not emphasized, but There is contribution in presentation problem
Teachers' Use of Technology	Training intensive For use digital tools by teachers	Use technology by teachers in support learning STEAM based	Use technology in the classroom For facilitate teaching	Use digital tools by teachers improve effectiveness learning	Learning based on technology support teaching creative teacher	Technology support implementation STEAM curriculum by teachers
21st Century Skills Evaluation Results	Improvement significant on creativity, thinking critical, collaboration, and communication	Focus on improvement creativity and thinking critical via STEAM	Increase collaboration, creativity, and thinking critical student	Focus on creativity and thinking critical student through experiment	Development skills collaboration and communication with technology	Improvement skills breakdown problem, thinking critical, and collaboration

Conclusion

Based on results research that has been done, can concluded that development of STEAM curriculum model based on technology own impact significant positive in increase skills 21st century on students, especially in aspect creativity, thinking critical, collaboration, and communication. Implementation technology in learning proven STEAM based can stimulate

student For think more innovative, analyzing problem in a way more deep, and increase ability they For Work The same in team and communicate ideas with a better way effective.

Improvement creativity (30%), thinking critical (25%), collaboration (20%), and communication (22%) showed that technology, if applied with appropriate in STEAM context, can enrich the learning process and provide more experience interesting and relevant for students. Learning based on technology allow student For involved direct in experiments, projects based on problems, and supporting simulation development skills practical required in the world of work 21st century.

Although results study show significant improvement, there is challenge in matter management time project based on technology and readiness necessary infrastructure considered by the school. Therefore that 's important For do revision more curriculum flexible, and provide training addition for teachers and students For ensure that technology can used in a way maximum and effective.

In general Overall, the STEAM curriculum is based on technology can become effective solution For prepare student with skills 21st century which is very much needed in the future. With existence strengthening in training and support technical, curriculum model This own potential big For increase quality education and provide student more supplies strong For face global challenges.

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We hope that this study can serve as a meaningful contribution to the field of education and provide practical insights for the advancement of future-ready learning models. Any suggestions and feedback for improvement are warmly welcomed.

References

- Aithal, P. S., & Maiya, A. K. (2023). Innovations in higher education industry–Shaping the future. *International Journal of Case Studies in Business, IT, and Education (IJCSBE)*, 7(4), 283-311.
- Ajani, O. A. (2024). Enhancing pre-service teacher education: Crafting a technology-responsive curriculum for modern classrooms and adaptive learners. *Research in*

- Belbase, S., Mainali, B. R., Kasemsukpipat, W., Tairab, H., Gochoo, M., & Jarrah, A. (2022). At the dawn of science, technology, engineering, arts, and mathematics (STEAM) education: prospects, priorities, processes, and problems. *International Journal of Mathematical Education in Science and Technology*, 53(11), 2919-2955. <https://doi.org/10.1080/0020739X.2021.1922943>
- Belbase, S., Mainali, B. R., Kasemsukpipat, W., Tairab, H., Gochoo, M., & Jarrah, A. (2022). At the dawn of science, technology, engineering, arts, and mathematics (STEAM) education: prospects, priorities, processes, and problems. *International Journal of Mathematical Education in Science and Technology*, 53(11), 2919-2955.
- Bhor, A., & Varghese, M. (2024). Steam-based teaching: Enhancing quality in education. *Journal of Education*, 11(2), 323-331.
- Damaševičius, R., & Sidekerskienė, T. (2024). Virtual worlds for learning in metaverse: A narrative review. *Sustainability*, 16(5), 2032. <https://doi.org/10.3390/su16052032>
- Erawan, G. M., Mariana, N., & Suryanti, S. (2025). Development and Challenges of STEAM Learning Implementation in Elementary Schools: A Comprehensive Literature Review. *International Journal of Emerging Research and Review*, 3(1), 000094-000094. <https://doi.org/10.56707/ijerar.v3i1.94>
- Fitria, T., Kuswanto, H., Dwandaru, W. S. B., Jumadi, J., Putri, D. P. E., & Juneid, A. Z. (2023). Perkembangan penelitian pendekatan STEAM pada pembelajaran fisika di indonesia: A systematic literature review. *Edusains*, 15(1), 1-17.
- Garlinska, M., Osial, M., Proniewska, K., & Pregowska, A. (2023). The influence of emerging technologies on distance education. *Electronics*, 12(7), 1550. <https://doi.org/10.3390/electronics12071550>
- Getenet, S., Cante, R., Redmond, P., & Albion, P. (2024). Students' digital technology attitude, literacy and self-efficacy and their effect on online learning engagement. *International Journal of Educational Technology in Higher Education*, 21(1), 3. <https://doi.org/10.1186/s41239-023-00437-y>
- Hadinugrahaningsih, T., Rahmawati, Y., Ridwan, A., Budiningsih, A., Suryani, E., Nurlitiani, A., & Fatimah, C. (2017). Keterampilan abad 21 dan STEAM (Science, Technology, Engineering, Art, and Mathematics) project dalam pembelajaran kimia. *LPPM Universitas Negeri Jakarta*, 110.
- Hamid, A., & Purnomo, M. S. (2025). The role of the principal as a human resource manager in improving the quality of education at Sunan Ampel Junior High School, Banyuwangi. *Educational Leadership Journal*, 6(01), 101-109.
- Hsu, Y. S., & Hwang, G. J. (2023). The effect of mobile technology-enhanced STEAM education on students' critical thinking and problem-solving skills. *Computers & Education*, 184, 104531. <https://doi.org/10.17275/per.25.63.12.5>
- Ismiati, N. (2024). Implementing STEAM education in the independent curriculum: Enhancing 21st century skills. *Tadibia Islamika*, 4(1), 21-27. <https://doi.org/10.28918/tadibia.v4i1.7238>

- Kang, N. H. (2019). A review of the effect of integrated STEM or STEAM (science, technology, engineering, arts, and mathematics) education in South Korea. *Asia-Pacific Science Education*, 5(1), 1-22. <https://doi.org/10.1186/s41029-019-0034-y>
- Khan, S. A., Nadim, M. A., & Poletti, G. (2025). Towards a new paradigm of steam in primary education as a 21st century skill. In *INTED2025 Proceedings* (pp. 750-758). IATED. <https://doi.org/10.21125/inted.2025.0283>
- Lafifa, F., Parno, P., Hamimi, E., & Setiawan, A. M. (2022, January). Development of STEM animation learning media with feedback to facilitate students' critical thinking ability on global warming materials. In *Eighth Southeast Asia Design Research (SEA-DR) & the Second Science, Technology, Education, Arts, Culture, and Humanity (STEACH) International Conference (SEADR-STEACH 2021)* (pp. 8-15). Atlantis Press. <https://doi.org/10.2991/assehr.k.211229.002>
- Laksmiwati, P. A., Lavicza, Z., Cahyono, A. N., Yunianto, W., & Houghton, T. (2023). Unveiling the implementation of STE (A) M Education: An exploratory case study of Indonesia from experts' and policymakers' perspectives. *Cogent Education*, 10(2), 2267959. <https://doi.org/10.1080/2331186X.2023.2267959>
- Leavy, A., Dick, L., Meletiou-Mavrotheris, M., Papparistodemou, E., & Stylianou, E. (2023). The prevalence and use of emerging technologies in STEAM education: A systematic review of the literature. *Journal of Computer Assisted Learning*, 39(4), 1061-1082. <https://doi.org/10.1111/jcal.12806>
- Lestari, D., Ibrahim, N., & Iriani, C. (2023). STEAM: Science, technology, engineering, art, and mathematics on history learning in the 21st century. *Journal of Education Research and Evaluation*, 7(2), 306-312. <https://doi.org/10.23887/jere.v7i2.44172>
- Ma, H., Li, L., Ma, Y., Liu, X., & Yang, S. (2025). Exploration and Application of Project-Based Teaching Integrating Scientific Research Achievements in Electronic Comprehensive Design Course. *Computer Applications in Engineering Education*, 33(3), e70047.
- Martinez, C. (2022). Developing 21st century teaching skills: A case study of teaching and learning through project-based curriculum. *Cogent Education*, 9(1), 2024936. <https://doi.org/10.1080/2331186X.2021.2024936>
- Nurhayati, E., Rizaldi, D. R., & Fatimah, Z. (2020). The Correlation of Digital Literation and STEM Integration to Improve Indonesian Students' Skills in 21st Century. *Online Submission*, 1(2), 73-80. <https://doi.org/10.46966/ijae.v1i2.36>
- Papadopoulou, E. A. (2024). Advancements in STEAM education for 21st century learners. *International Journal of Education*, 16(4), 39-70. <https://doi.org/10.5296/ije.v16i4.22270>
- Park, W., & Cho, H. (2022). The interaction of history and STEM learning goals in teacher-developed curriculum materials: opportunities and challenges for STEAM education. *Asia Pacific Education Review*, 23(3), 457-474. <https://psycnet.apa.org/doi/10.1007/s12564-022-09741-0>
- Ramaila, S., & Molwele, A. J. (2022). The Role of Technology Integration in the Development of 21st Century Skills and Competencies in Life Sciences Teaching and Learning. *International Journal of Higher Education*, 11(5), 9-17. <https://doi.org/10.5430/ijhe.v11n5p9>

- Reyes, R. L., Isleta, K. P., Regala, J. D., & Bialba, D. M. R. (2024). Enhancing experiential science learning with virtual labs: A narrative account of merits, challenges, and implementation strategies. *Journal of Computer Assisted Learning*, 40(6), 3167-3186. <https://psycnet.apa.org/doi/10.1111/jcal.13061>
- Saad, A., & Zainudin, S. (2024). A review of teaching and learning approach in implementing Project-Based Learning (PBL) with Computational Thinking (CT). *Interactive Learning Environments*, 32(10), 7622-7646. <https://doi.org/10.1080/10494820.2024.2328280>
- Safitri, N. A. (2022). The steam approach to improve 21st century skills in elementary schools. *Kalam Cendekia: Jurnal Ilmiah Kependidikan*, 10(2), 227-233. <https://doi.org/10.20961/jkc.v10i2.65493>
- Scholkmann, A., Stegeager, N., & Miller, R. K. (2023). Integrating the Integration: The Role and Challenges of Problem-Based Learning in Bringing Together Social Science and Humanities (SSH) and Science, Technology, Engineering and Mathematics (STEM). *Journal of Problem Based Learning in Higher Education*, 11(1), 98-123. <https://doi.org/10.54337/ojs.jpblhe.v11i1.7371>
- Serrano-Ausejo, E., & Mårell-Olsson, E. (2024). Opportunities and challenges of using immersive technologies to support students' spatial ability and 21st-century skills in K-12 education. *Education and Information Technologies*, 29(5), 5571-5597. <https://doi.org/10.1007/s10639-023-11981-5>
- Smith, K., Maynard, N., Berry, A., Stephenson, T., Spiteri, T., Corrigan, D., ... & Smith, T. (2022). Principles of problem-based learning (PBL) in STEM education: Using expert wisdom and research to frame educational practice. *Education Sciences*, 12(10), 728. <https://doi.org/10.3390/educsci12100728>
- Sunanih, S., Maulidah, N., Sunhaji, S., & Mutijah, M. (2025). Resource limitations and teacher training challenges in implementing the steam-based merdeka curriculum for kindergarten's cognitive and creative development. *Jurnal Konseling dan Pendidikan*, 13(1), 363-377. <https://doi.org/10.29210/1133200>
- Wannapiroon, N., & Pimdee, P. (2022). Thai undergraduate science, technology, engineering, arts, and math (STEAM) creative thinking and innovation skill development: a conceptual model using a digital virtual classroom learning environment. *Education and Information Technologies*, 27(4), 5689-5716. <https://doi.org/10.1007/s10639-021-10849-w>
- Wu, W. C., & Chen, C. Y. (2021). A framework for enhancing critical thinking in STEAM education using digital tools. *Journal of Science Education and Technology*, 30(4), 445-459.
- Xin, Y., & Chen, Z. (2025, May). Research on cross disciplinary practice of creative design curriculum in the era of cultural and technological integration. In *International Conference on Human-Computer Interaction* (pp. 128-145). Cham: Springer Nature Switzerland.
- Yılmaz, A. (2021). The effect of technology integration in education on prospective teachers' critical and creative thinking, multidimensional 21st century skills and academic achievements. *Participatory Educational Research*, 8(2), 163-199.

- Zakir, S., Hoque, M. E., Susanto, P., Nisaa, V., Alam, M. K., Khatimah, H., & Mulyani, E. (2025, June). Digital literacy and academic performance: the mediating roles of digital informal learning, self-efficacy, and students' digital competence. In *Frontiers in Education* (Vol. 10, p. 1590274). Frontiers Media SA. <https://doi.org/10.3389/feduc.2025.1590274>
- Zhang, H., Liu, C., & Zhao, H. (2022). The role of technology in supporting STEAM education: A systematic review. *Computers in Human Behavior*, 128, 107051. <https://doi.org/10.59828/ijrmst.v3i4.199>