Infinity Journal of Mathematics Education
Volume 14, No. 2, 2025
p-ISSN 2089-6867
e–ISSN 2460-9285
https://doi.org/10.22460/infinity.v14i2.p283-302

STEAM approach in project-based learning to develop mathematical literacy and students' character

In In Supianti[1], Poppy Yaniawati[1*], Ebenezer Bonyah[2], Astri Widiastuti Hasbiah[3], Nisrina Rozalini[1]

[1]Department of Mathematics Education, Universitas Pasundan, West Java, Indonesia
[2]Department of Mathematics Education, Akenten Appiah Menka University of Sills Training and Entrepreneurial Development Kumasi, Ghana
[3]Department of Environmental Engineering, Universitas Pasundan, West Java, Indonesia
[*]Correspondence: pyaniawati@unpas.ac.id

Received: Sep 29, 2024 | **Revised**: Dec 14, 2024 | **Accepted**: Dec 16, 2024 | **Published Online**: Jan 26, 2025

Abstract

Mathematics is essential for individuals to solve everyday life problems. However, students remain insufficiently motivated in mathematics learning, necessitating the implementation of engaging teaching approaches integrated with other disciplines, such as STEAM (Science, Technology, Engineering, Art, and Mathematics). This study investigated the effectiveness of a STEAM-based Project-Based Learning (PjBL) approach on mathematical literacy and character development among secondary school students. Utilizing a mixed-methods convergent parallel design, the research employed quantitative and qualitative techniques. The quantitative data collection used a literacy skills test to measure mathematical literacy. Meanwhile, the qualitative data collection to measure students' character utilized surveys, interviews, and observations. Quantitative data analysis was conducted using the Kruskal-Wallis test, while qualitative data analysis employed triangulation, including data reduction, data presentation, and data verification stages. The study results revealed that students' mathematical literacy significantly improved after participating in STEAM-PjBL-based learning. Additionally, STEAM-PjBL fosters the development of students' character traits, including teamwork, communication, and responsibility, highlighting its potential to support holistic educational outcomes. These findings indicate that integrating STEAM principles with PjBL enhances academic performance and cultivates critical 21st-century skills.

Keywords:
Character development, Literacy skills, Project-based learning, STEAM-based learning

How to Cite:
Supianti, I. I., Yaniawati, P., Bonyah, E., Hasbiah, A. W., & Rozalini, N. (2025). STEAM approach in project-based learning to develop mathematical literacy and students' character. *Infinity Journal*, *14*(2), 283-302. https://doi.org/10.22460/infinity.v14i2.p283-302

1. INTRODUCTION

The effectiveness of STEAM-based learning materials through project-based learning (PjBL) to develop student character and literacy skills has garnered significant attention in educational research. STEAM, which integrates Science, Technology, Engineering, Arts, and Mathematics, has been recognized as a highly effective pedagogical approach for developing mathematical literacy and character in students (Albeshree et al., 2022; Hardman, 2019; Nantschev et al., 2020; Ní Shé et al., 2023). By incorporating real-world applications, STEAM connects mathematical concepts to practical experiences, making learning more engaging and relevant (Herrero et al., 2023; Herro et al., 2022; Körtesi et al., 2022; Ozkan & Umdu Topsakal, 2021; Rodríguez-Nieto & Alsina, 2022). This interdisciplinary and hands-on methodology fosters an environment where problem-solving skills, creativity, and critical thinking can thrive, providing opportunities to explore mathematical concepts through practical projects. Furthermore, STEAM-based learning promotes essential character traits, such as collaboration, communication, and resilience (Boice et al., 2021; Conradty & Bogner, 2020; Kim et al., 2019; Li et al., 2022; Quigley et al., 2020). Engaging students in collaborative projects encourages them to work together, navigate challenges, and respect diverse perspectives, ultimately fostering empathy and leadership skills. As students participate in project-based learning activities, they develop a growth mindset, viewing challenges as integral to the learning process (Bai & Wang, 2023; Chen, 2021; Yeager & Dweck, 2020; Yeager et al., 2019).

Despite the proven benefits, the implementation of STEAM-based learning in educational settings, particularly at the junior high school level, remains limited. Traditional mathematics instruction often emphasizes rote memorization, which can result in a lack of engagement and understanding of real-world applications (Pellegrini et al., 2021). The general solution to this issue is integrating STEAM-based learning materials through Project-Based Learning (PjBL), offering an interactive platform for students to apply mathematical concepts in real-world scenarios (Cunha et al., 2024). By integrating STEAM with PjBL, students engage in inquiry-based learning, collaboration, and hands-on activities, making learning more meaningful and engaging.

Research indicates that the combination of STEAM with PjBL significantly enhances conceptual understanding and practical skills, especially in complex topics (Chistyakov et al., 2023; Diego-Mantecon et al., 2021). For instance, students working on projects like designing structures can employ mathematical skills such as geometry and algebra, thus deepening their understanding of these concepts in a practical context (Gellert et al., 2013; Ziatdinov & Valles, 2022). This interdisciplinary nature encourages a holistic approach to learning, where the integration of arts within STEAM allows students to approach mathematical problems creatively, viewing them from multiple perspectives (Iyer et al., 2023). This enhances their mathematical literacy and helps develop social and emotional skills through collaboration and communication (Aleksić et al., 2019).

Character is an essential soft skill to develop in the school learning process (Fisher et al., 2017; Kariadinata et al., 2019). Particularly in STEAM-based PjBL, the strength of character is highly needed, as students learn to work in teams, build resilience, and appreciate diverse perspectives. The integration of character education within the STEAM curriculum

fosters a sense of responsibility and ethical reasoning, which is essential for their development as informed citizens (Ng, 2024; Rahmawati et al., 2022). Engaging students in project-based learning that addresses real-world challenges helps them develop social responsibility alongside academic learning. Moreover, STEAM-based PjBL has a positive impact on students' attitudes toward mathematics by making learning relevant and enjoyable (Cunha et al., 2024). By integrating arts and digital literacy into the STEAM framework, students can engage more effectively, as they become accustomed to utilizing various media and collaborative learning environments, which promotes the holistic development of literacy and character (Silawati, 2019). This interdisciplinary approach also helps enhance literacy skills, as projects involving information delivery or multimedia presentations require clear articulation and effective communication (Bertrand & Namukasa, 2020).

The Merdeka Curriculum policy includes the minimum competency assessment and character surveys. This assessment emphasizes literacy and numeracy skills (Alwiyah & Imaniyati, 2018). Mathematical literacy is considered one of the abilities that can help the younger generation meet the demands of the current global development (Supianti et al., 2022; Yaniawati et al., 2023) and is an important skill for students (Gabriel et al., 2020; Hadiyanti et al., 2021; Stacey, 2015). Mathematical literacy refers to the ability to formulate, use, and interpret mathematics in various situations (Wijaya et al., 2024). It can also be defined as the ability to understand problems related to mathematics and apply them in daily life (Kurniawati et al., 2020; Mahlow & Hediger, 2021); the ability to analyze, argue, and effectively communicate ideas in solving mathematical problems (Andriyani et al., 2022); and it can also mean using mathematical knowledge to solve and interpret problems (Wijaya et al., 2024).

The students' mathematical literacy issues in Indonesia have been low from 2000 to 2018, ranking in the bottom 10 among OECD member countries eight times (Wijaya et al., 2024). The low mathematical literacy of students must be taken seriously, as this skill is important for using mathematics to solve daily problems (Effendi et al., 2020; Kozakli Ulger et al., 2022; Kurniawati et al., 2020; Murtiyasa & Perwita, 2020). One of the factors contributing to low mathematical literacy is the lack of engaging teaching methods used by teachers in the classroom (Setiawati et al., 2017). Besides teacher readiness, factors like curriculum and learning models (Murtiyasa & Perwita, 2020) also play a role. Incorrect use of learning media can also be a factor contributing to the low mathematical literacy of students.

In addition to mathematical literacy, student character is also a concern for all education stakeholders in Indonesia. Currently, many cases show a decline in student character, such as brawls, bullying, and even murders committed by minors. Research results indicate that students have low resilience in learning (Khairani & Mudjiran, 2022) and show limited participation in learning activities (Angraini & Sriyati, 2019). This forms the basis for the promotion of character and moral education in Indonesia.

To address the problems above, an effective STEAM learning design is needed to develop students' mathematical literacy and character. Based on research findings by Novita and Herman (2021) and Hsu (2020) integrating educational technology into learning can develop students' mathematical literacy skills, academic achievement, and learning

effectiveness (Akman & Çakır, 2023; Shi et al., 2022). STEAM builds a bridge between what is learned and real life, helping students understand what they are learning (Zhang et al., 2024). Mathematical literacy is relevant to the ethnomathematics of the Sundanese community in terms of content, context, and mathematical processes (Umbara et al., 2023). STEAM-based learning materials, when combined with PjBL, have shown considerable promise for developing student character and literacy skills. This approach fosters critical thinking, creativity, and collaboration among students, while also promoting character development and literacy skills essential for success in the 21st century (Aguilera & Ortiz-Revilla, 2021; Becker & Park, 2011). Mathematical literacy can be improved through realistic mathematics education (Fauzan et al., 2024).

The objectives of this research are: 1) to design STEAM-based learning that emphasizes the development of students' mathematical literacy and character; 2) to analyze the mathematical literacy and character development of students who engage with STEAM-based learning; and 3) to assess the effectiveness of STEAM-based learning in enhancing students' mathematical literacy and character.

2. METHOD

This research employed a mixed-method approach with a convergent parallel design. The quantitative method was used to analyze the effectiveness of STEAM-based learning in improving mathematical literacy, while the qualitative approach described the implementation of STEAM-based learning in developing students' character.

The quantitative data collection used a literacy skills test to measure mathematical literacy. Meanwhile, the qualitative data collection to measure students' character utilized, interviews, and observations. The documentation study collected literature and analyzed the implementation of STEAM-based learning and the variables under study, which included mathematical literacy and student characteristics. Observations involved both educators and students to observe the implementation of STEAM learning by teachers and student character. Interviews were conducted with students to gain deeper insights into the use of STEAM learning, mathematical literacy, and student character. The mathematical literacy test consisted of six open-ended questions that addressed the indicators of formulating, employing, and interpreting.

Quantitative data analysis was conducted using the Kruskal-Wallis test, while qualitative data analysis employed triangulation, including data reduction, data presentation, and data verification stages. Qualitative data analysis was conducted through triangulation, including stages of data reduction, data presentation, and data verification. Additionally, it employed the Interactive Analysis model by Yaniawati and Indrawan (2024), which involves: 1) recording all observed phenomena in the field through observations, interviews, and documentation; 2) reviewing the observation, interview, and documentation notes, separating relevant data, and repeating this process to check for classification errors; 3) describing the classified data with attention to the research focus and objectives; and 4) producing a final analysis in the form of a research report.

The research subjects are High School with two classes, each with 24 students from junior high school. The research stages included preparation through FGDs, designing

research instruments, creating STEAM-based learning designs to enhance mathematical literacy and student character, expert validation, analyzing validation results, conducting STEAM-based learning trials, and formulating the concept and characteristics of STEAM-based learning.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Design of STEAM-Based Learning for Ratio Material

The STEAM-based learning design for ratio material covers various interdisciplinary aspects. Within the science component, students explore basic physics concepts related to force, motion, and energy, which are necessary for moving simple toy cars. Additionally, they examine the properties of materials used in constructing cars, considering aspects such as strength, flexibility, and the durability of recycled materials. The technology and art component involves students using basic technology to design and visualize their toy cars. This process includes utilizing graphic design applications or simulation software, which enables them to focus on the car's aesthetic aspects, appreciating the value of beauty and artistry in their creations. In the engineering phase, students develop a step-by-step process for constructing their toy cars, starting from collecting recycled materials to final assembly. This practical exercise emphasizes the importance of sustainable practices, as they are tasked with building the cars using recycled materials. The mathematics component is integrated as students apply various ratio concepts. They explore direct proportions in the design process, analyze inverse proportion between energy and speed, calculate material efficiency ratios, and compare costs, allowing them to grasp the mathematical foundations that underpin their project (see Figure 1).

Science • Basic physics concepts related to force, motion, and energy necessary for moving simple toy cars. • Material properties used in the car, such as strength, flexibility, and durability of recycled materials.	**Technology and Art** • Students use simple technology to design and visualize the toy car, using graphic design applications or simulation software. • Aesthetic values and the beauty of the toy car.
Engineering • Outlining the steps in car construction, from gathering recycled materials to assembly. • Building toy cars from recycled materials.	**Mathematics** • Direct proportion in car design. • Inverse proportion in energy and speed. • Efficiency ratio of material usage. • Cost comparison ratio.

Figure 1. STEAM-based learning design for ratio topics

The integration of STEAM and character elements within the Ratio lesson materials is illustrated in the following Figure 2.

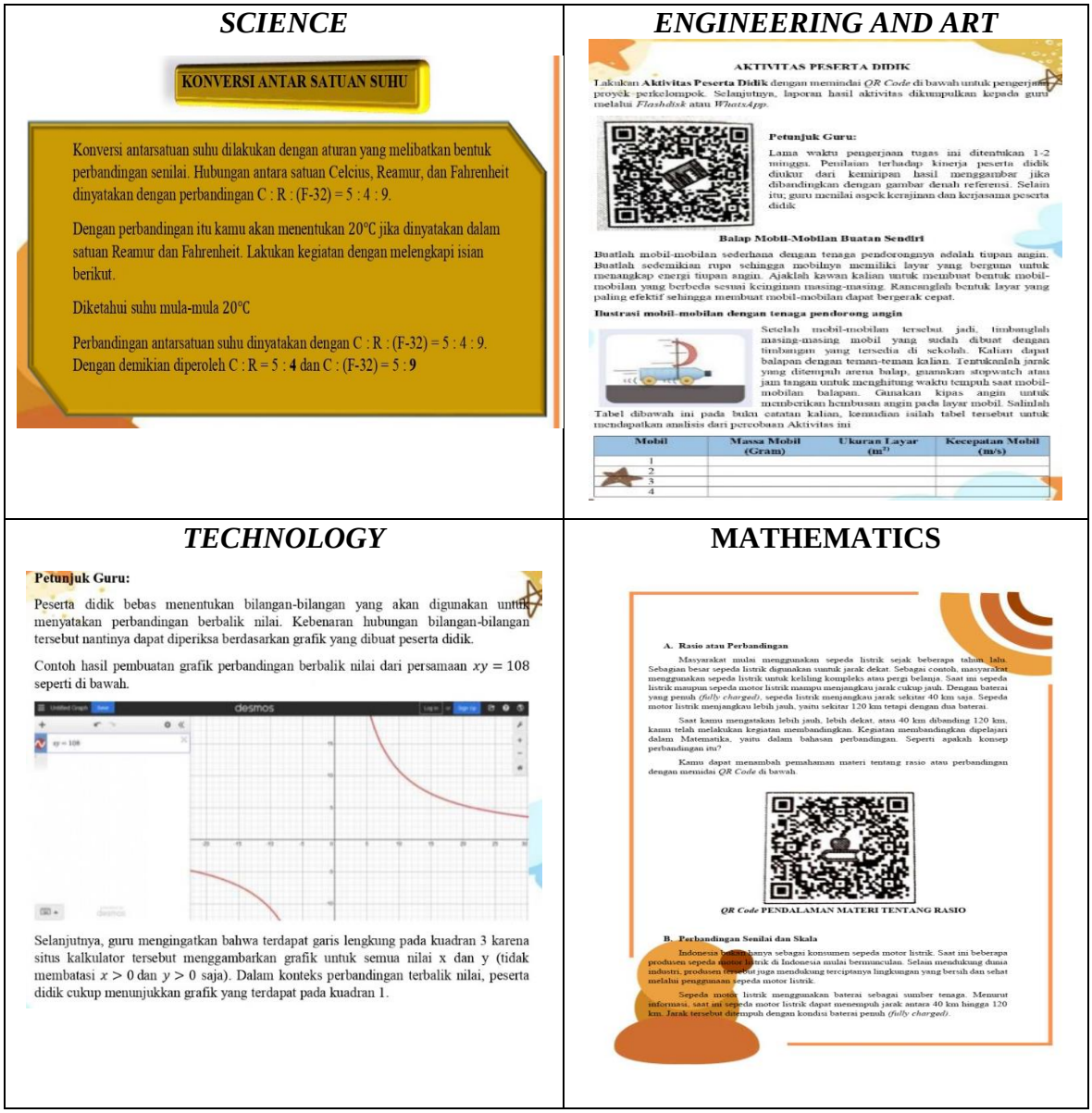

Figure 2. Integration of STEAM in ratio topics

3.1.2. Mathematical Literacy Test Results

The results validated STEAM-based materials. The average effect size was 0.51, indicating moderate effectiveness based on Cohen's criteria. Table 1 shows the mathematical literacy based on student character

Table 1. Mathematical literacy skills based on student character

Treatment	Character Group	Mean	Std. Deviation
Conventional Method	Low	0.00	0.00
	Moderate	4.38	1.77
	High	8.13	3.72
Total		4.17	4.08

Treatment	Character Group	Mean	Std. Deviation
STEAM-Based Materials (PjBL)	Low	45.00	14.14
	Moderate	61.88	2.59
	High	75.00	5.35
Total		60.63	15.13

A normality and homogeneity test of the data revealed non-normal and non-homogeneous distributions. Consequently, a non-parametric Kruskal-Wallis test yielded a statistic of 9.272 with a degree of freedom (df) of 2 and an Asymptotic Significance (Sig.) of 0.010. Since $p < 0.05$, these results indicate significant differences in literacy test scores among students based on their character levels (low, moderate, high). Studies by Sukmawati et al. (2023) showed that Project-Based Learning integrated with STEAM fosters 21st-century skills development, including communication, science literacy, critical thinking, creative thinking, and scientific processing skills. Similarly, Indahwati et al. (2023) found that STEAM-based PjBL effectively enhances students' critical thinking skills. This aligns with the present study, which suggests that PjBL-STEAM improves students' mathematical abilities.

The STEAM approach based on Project-Based Learning (PjBL) was implemented by involving students in interdisciplinary projects that integrated science, technology, engineering, arts, and mathematics to solve real-world problems. These collaborative activities significantly enhanced students' mathematical literacy. This improvement occurred as students were trained to connect abstract concepts with practical situations, comprehend the applications of mathematics in daily life, and develop their communication and collaboration skills.

3.1.3. Student Character Survey Results

The results of the character survey, which comprised 30 statements across four indicators, demonstrate a significant enhancement in student character development facilitated by the STEAM-based Project-Based Learning (PjBL) approach. Table 2 highlights the substantial differences in mean scores between students exposed to conventional methods and those engaged with STEAM-PjBL across varying levels of character strength.

Table 2. Student character survey results

Method	Character Group	Mean	Std. Deviation
Conventional Method	Weak	66.88	3.68
	Moderate	75.38	1.30
	Strong	81.38	5.76
Total		74.54	7.19

Method	Character Group	Mean	Std. Deviation
STEAM-Based Materials (PjBL)	Weak	97.38	6.76
	Moderate	111.00	1.77
	Strong	120.88	3.21
Total		109.75	10.72

The data indicate that the STEAM-PjBL method significantly outperformed the conventional approach across all character groups. Specifically, students in the weak character category under STEAM-PjBL exhibited a remarkable increase, achieving a mean score of 97.38 compared to 66.88 under the conventional approach. Similarly, those in the moderate and strong character categories scored substantially higher under the STEAM-PjBL model, with mean scores of 111.00 and 120.88, respectively, as opposed to 75.38 and 81.38 with traditional methods. This consistent improvement across character levels suggests that the STEAM-PjBL method effectively nurtures character development more broadly than conventional pedagogical methods.

To substantiate the statistical relevance of these findings, a two-way ANOVA was conducted. The analysis confirmed that the STEAM-PjBL approach significantly influenced character development ($F(5,42) = 200.168$, $p < 0.001$), with an R^2 value of 0.960, indicating that the model explained 96% of the variance in character development outcomes. The high effect size (Partial Eta Squared = 0.952) for the learning method variable underscores the substantial impact of the STEAM-PjBL method on character development, independent of initial character strength levels. Furthermore, the interaction between instructional method and character category ($F(2,42) = 4.545$, $p = 0.016$, Partial Eta Squared = 0.178) suggests that the effectiveness of STEAM-PjBL is particularly pronounced among students with differing initial character traits. These results validate the hypothesis that the STEAM-PjBL model not only fosters cognitive development but also has a significant positive impact on the cultivation of student character, enhancing traits such as collaboration, resilience, and adaptability across diverse character strengths.

Each stage in the STEAM-PjBL learning process was designed to support the development of students' character according to relevant indicators as follows: 1) In the project planning stage, students were encouraged to identify real-world problems and design solutions using the STEAM approach, which developed skills in collaboration, responsibility, and initiative; 2) In the investigation and exploration stage, students engaged in in-depth research to understand the context of the problem, gather data, and explore STEAM concepts, thus sharpening their curiosity, critical thinking, and work ethic; 3) During the project implementation stage, students applied STEAM concepts in creating tangible products or solutions, which reinforced their resilience, creativity, and discipline; 4) The presentation and reflection stage provided students with the opportunity to present their project outcomes and reflect on the process they had undergone, thereby developing communication skills, empathy, and appreciation for team contributions; 5) In the evaluation stage, both teachers and students evaluated the success of the project based on predetermined

indicators, strengthening values such as honesty, openness to feedback, and lifelong learning.

3.1.4. Student Observations

The observation measured cooperation, expressing opinions, and answering questions, with most students rated as "Good" (average score 84.3). Students showed excellent involvement, particularly in cooperation (average 86.00), followed by expressing opinions (average 84.13) and answering questions (average 82.88). The observation analysis provides a nuanced view of student engagement, particularly in cooperative learning, opinion expression, and responsiveness to questions. Across these dimensions, students demonstrated a high level of involvement, with an overall average score of 84.3, categorized as "Good." The data revealed particularly strong performance in cooperative learning, with an average score of 86.00, indicating that students were highly effective in collaborative settings. This is followed closely by the aspect of expressing opinions, with an average score of 84.13, suggesting a robust engagement in articulating thoughts and participating actively in discussions. The dimension of answering questions also exhibited positive outcomes, with an average score of 82.88, underscoring students' willingness to engage with instructional content and interactively respond during learning activities.

These findings collectively indicate that the instructional environment fostered by the STEAM-based Project-Based Learning (PjBL) approach is conducive to active and cooperative engagement, where students not only collaborated effectively but also felt encouraged to contribute personal insights and respond thoughtfully to instructional prompts. This level of engagement aligns with the educational aims of PjBL, which emphasizes collaboration and active participation as fundamental components of the learning process. The data thereby supports the argument that the PjBL framework within STEAM education enhances essential soft skills such as teamwork, self-expression, and interactive responsiveness, which are critical to comprehensive educational outcomes. Observations assessed collaboration, expressing opinions, and answering questions, with an overall average score of 84.3 ("Good" category). Most students performed well, with only one student in the "Sufficient" category (score of 70). No students were in the "Poor" or "Very Poor" categories, indicating a generally positive class performance.

The STEAM-PjBL learning approach demonstrated high student engagement in cooperation, expressing opinions, and answering questions. Students exhibited excellent performance in collaborating, actively participating in discussions, and responding well to questions. These findings indicated that the PjBL approach supported active and collaborative involvement, encouraging students to contribute personal insights and interact constructively during learning. This suggests that the STEAM-PjBL was effective in developing students' collaboration, self-expression, and responsiveness skills.

3.1.5. Interview Results

The interview results reveal key insights into students' perceptions of mathematics and their experiences with the STEAM-based Project-Based Learning (PjBL) approach. The findings indicate that many students perceive mathematics as a challenging and unengaging

subject, often characterized by its complexity and lack of real-world relevance. This sentiment underscores a critical need for more creative and contextualized instructional approaches that can demystify mathematical concepts and make them more accessible and relevant to students' lives. The interview responses also highlight a predominant reliance on traditional learning materials, such as textbooks and worksheets, which students generally regarded as insufficiently interactive. This reliance on conventional resources appears to contribute to the negative perceptions of mathematics, as these materials may not adequately stimulate student interest or encourage active engagement with the subject matter.

In contrast, students expressed a strong preference for the STEAM-PjBL approach, citing its interdisciplinary nature and its ability to link mathematical concepts with real-world applications. This preference suggests that STEAM-PjBL not only makes mathematics more relatable but also enhances its perceived value by illustrating how mathematical principles underpin various aspects of daily life and broader scientific and technological contexts. Students reported that the hands-on, project-based elements of STEAM-PjBL fostered higher levels of engagement and were instrumental in developing essential skills such as confidence, communication, and collaboration. These findings align with existing literature, which emphasizes the role of experiential learning in promoting deeper understanding and sustained interest in STEM fields.

The data thus suggest that the STEAM-PjBL framework effectively addresses both cognitive and affective barriers to learning mathematics. By providing an interactive, context-rich learning environment, this approach not only improves mathematical comprehension but also cultivates essential interpersonal skills, ultimately contributing to a more holistic educational experience. These outcomes underscore the potential of STEAM-PjBL to transform student perceptions of mathematics and highlight its value as a pedagogical model capable of fostering both academic and personal growth.

3.2. Discussion

The design of STEAM-based learning enables students to engage interactively through problem-based projects (PjBL). For instance, a project involving the creation of a toy car from recycled materials incorporates concepts of ratio and proportion, facilitating practical application and deepening students' understanding of mathematics. Additionally, the integration of arts and technology in this learning approach underscores the importance of creativity and aesthetics at every stage of project design and development. Bertrand and Namukasa (2020) assert that STEAM education fosters a learning environment centered on sustainability and collaboration, encouraging students to engage in real-world tasks requiring critical thinking and teamwork.

This approach also highlights the crucial role of technology in fostering creativity. In the toy car project, students can use graphic design applications or simulation software to visualize the final product, introducing them to technological tools while teaching them to think visually and artistically. Aguilera and Ortiz-Revilla (2021) emphasize that the arts within STEAM help students link abstract concepts to real-world applications, enhancing their engagement with mathematical learning.

Students' mathematical literacy improves significantly with STEAM-based methods compared to conventional approaches. Through hands-on projects like toy car creation, students could apply ratio and proportion concepts in real-life contexts, making mathematics more relevant and accessible, thereby reducing perceptions of it as an abstract and challenging subject. The findings of Ishartono et al. (2024) indicate that the STEAM-integrated Flip Flop model significantly enhances students' understanding of the concept of composition functions compared to the conventional model. STEAM enhances creative thinking abilities, including fluency, flexibility, originality, and elaboration (Ahmad et al., 2021; Chang et al., 2023; Suganda et al., 2021; Witdiya et al., 2023). STEAM-based learning was able to enhance students' creative thinking skills, particularly when integrated with environmental concepts (Suganda et al., 2021). Using STEAM education in learning positively impacts students' creative thinking abilities, leading to a significant average increase in learning outcomes (Ahmad et al., 2021). Integrating STEAM into project-based learning significantly improves students' creativity and computational thinking skills in medium and hard tasks compared to regular curriculum (Chang et al., 2023). STEAM learning has a very favorable effect on students' creative thinking abilities in physics learning, with elaboration and originality indicators showing the highest improvement (Witdiya et al., 2023).

STEAM significantly impacting students' critical thinking skills (Kadir et al., 2023; Putri et al., 2023). The STEAM-based discovery learning model positively impacts students' critical thinking skills, enhancing their learning experience in school (Kadir et al., 2023). STEAM-based blended learning effectively improves students' critical and creative thinking skills, with higher improvements in experimental classes compared to control classes (Putri et al., 2023). STEAM also improves mathematical reasoning abilities (Duo-Terron et al., 2022; Siregar et al., 2023). Implementing an integrated STEAM Project via mobile technology significantly improves elementary school students' Mathematical Reasoning ability (Siregar et al., 2023). STEAM in primary education improves linguistic and mathematical competencies, particularly in speaking, oral comprehension, and calculation, with a positive correlation between reading comprehension and problem-solving (Duo-Terron et al., 2022). Students' behavior in mathematical problem-solving can be categorized into naive, routine, semi-sophisticated, and sophisticated behaviors, with some being able to direct to sophisticated behavior (Harisman et al., 2021).

Beyond cognitive skills, STEAM is also effective in character development. Collaborative activities that require teamwork help students appreciate the value of cooperation and effective communication. For example, in the toy car project, students must communicate with team members to achieve optimal results while learning to respect diverse ideas and opinions. Wahba et al. (2022) emphasize that STEAM-based projects offer opportunities for students to enhance their metacognitive awareness in mathematics. Furthermore, the coordinated and transversal use of STEAM improves students' linguistic and mathematical competencies, particularly in speaking, listening comprehension, and calculation (Duo-Terron et al., 2022). STEAM also boosts students' project skills and learning motivation (Lin & Tsai, 2021).

STEAM has proven more effective than conventional methods in enhancing mathematical literacy and character development. This approach allows students to practice learned concepts in real-life situations, moving beyond theoretical or written exercises. Aguilera and Ortiz-Revilla (2021) indicate that implementing STEAM in education enhances mathematical understanding while fostering creativity and innovation. Students using digital STEAM learning show better learning performance and lower cognitive load compared to conventional methods (Chen & Huang, 2023). By presenting real-world challenges, students are motivated to think critically and creatively to find solutions.

From a character development perspective, STEAM emphasizes values such as collaboration, perseverance, and responsibility. Students working in teams learn to appreciate differences and work together towards shared goals. These findings align with theories suggesting that collaborative learning experiences help develop students' social and emotional skills, which are essential for success in both professional and personal lives. Li et al. (2022) state that the STEAM learning model facilitates meaningful integration of disciplines and independence in learning. STEAM training programs for teachers improve collaboration, pedagogy, and arts integration practices among educators (Boice et al., 2021). STEAM at the elementary level can develop basic technical and scientific competencies, such as problem-solving, applying creative ideas, and taking responsibility (Dostál et al., 2022).

In summary, this study demonstrates that integrating STEAM into educational curricula significantly benefits students' mathematical literacy and character development. This approach not only enhances cognitive competencies but also helps students develop interpersonal skills and a sense of social responsibility. STEAM creates a more dynamic and interactive learning environment, motivating students to engage more deeply in the learning process (Hsiao & Su, 2021; Jesionkowska et al., 2020). The integration of arts and technology in mathematics learning makes abstract concepts more accessible and relevant to everyday life, ultimately improving learning outcomes and student engagement (Cai, 2023; Chen & Huang, 2023).

These findings highlight the importance of adopting the STEAM approach in modern education. In addition to improving academic outcomes, STEAM facilitates the development of essential social skills and character needed to tackle global challenges (Başaran & Bay, 2023; Conradty & Bogner, 2020). Schools and teachers are thus encouraged to integrate STEAM more actively into the curriculum and create project-based learning experiences relevant to real life. In this way, students evolve not only as intellectually competent individuals but also as creative, collaborative, and responsible individuals.

4. CONCLUSION

The STEAM-based learning design on ratio topics integrates the concepts of science, technology, engineering, arts, and mathematics in a project to create toy cars from recycled materials. From the science aspect, students learn the fundamentals of physics related to force, motion, and the energy required to move the car, as well as evaluating material properties like the strength and flexibility of repurposed materials. In the technology and arts components, students utilize graphic or simulation applications to design and visualize the

car's structure, combining both aesthetic and functional aspects. The engineering process emphasizes construction steps, from material collection to assembly, highlighting sustainability. In mathematics, students apply direct and inverse proportions, evaluate material efficiency ratios, and analyze cost comparisons in car design.

Students' mathematical literacy significantly improved after participating in STEAM-based learning. Through project activities, they could apply mathematical theories in practical tasks, such as calculating material proportions and measuring design efficiency. Additionally, STEAM fosters the development of students' character traits, including teamwork, communication, and responsibility. Thus, STEAM not only enhances academic skills but also shapes the character and motivation essential for success in education and everyday life.

STEAM-based learning has proven effective in enhancing students' mathematical literacy and character development. By integrating diverse disciplines and collaborative approaches, this method strengthens mathematical understanding while building social skills such as communication, cooperation, and perseverance. Students become more actively engaged in the learning process, finding real-life relevance in mathematics, and experiencing positive character growth across all categories. Furthermore, there is a positive correlation between character and cognitive skills, indicating mutual reinforcement between these aspects. The long-term impact is that students become more adaptive and prepared to face future challenges, whether in higher education or professional life.

Acknowledgments

The authors would like to express our sincere gratitude to the Direktorat Riset, Teknologi dan Pengabdian kepada Masyarakat, Kementerian Pendidikan dan Kebudayaan Republik Indonesia for providing the financial support that made this research possible. Their funding and assistance have been instrumental in the successful completion of this study. We also extend our appreciation to all individuals and institutions that contributed to this project in any capacity.

Declarations

Author Contribution : IIS: Conceptualization, Data curation, Methodology, Project administration, and Writing - original draft; PY: Conceptualization, and Writing - review & editing; EB: Writing - review & editing; AWH: Writing - review & editing; NR: Formal analysis, and Investigation.

Funding Statement : This research was funded by Direktorat Riset, Teknologi dan Pengabdian kepada Masyarakat, Kementerian Pendidikan dan Kebudayaan Republik Indonesia.

Conflict of Interest : The authors declare no conflict of interest.

Additional Information : Additional information is available for this paper.

REFERENCES

Aguilera, D., & Ortiz-Revilla, J. (2021). STEM vs. STEAM education and student creativity: A systematic literature review. *Education Sciences*, *11*(7), 331. https://doi.org/10.3390/educsci11070331

Ahmad, D. N., Astriani, M. M., Alfahnum, M., & Setyowati, L. (2021). Increasing creative thinking of students by learning organization with steam education. *Jurnal Pendidikan IPA Indonesia*, *10*(1), 103-110. https://doi.org/10.15294/jpii.v10i1.27146

Akman, E., & Çakır, R. (2023). The effect of educational virtual reality game on primary school students' achievement and engagement in mathematics. *Interactive Learning Environments*, *31*(3), 1467-1484. https://doi.org/10.1080/10494820.2020.1841800

Albeshree, F., Al-Manasia, M., Lemckert, C., Liu, S., & Tran, D. (2022). Mathematics teaching pedagogies to tertiary engineering and information technology students: a literature review. *International Journal of Mathematical Education in Science and Technology*, *53*(6), 1609-1628. https://doi.org/10.1080/0020739X.2020.1837399

Aleksić, G., Merrell, C., Ferring, D., Tymms, P., & Klemenović, J. (2019). Links between socio-emotional skills, behavior, mathematics and literacy performance of preschool children in Serbia. *European Journal of Psychology of Education*, *34*(2), 417-438. https://doi.org/10.1007/s10212-018-0387-8

Alwiyah, D., & Imaniyati, N. (2018). Keterampilan mengajar guru dan kesiapan belajar siswa sebagai determinan terhadap hasil belajar siswa [Teacher teaching skills and student learning readiness as determinants of student learning outcomes]. *Jurnal Manajerial*, *17*(1), 95-103. https://doi.org/10.17509/manajerial.v17i1.9767

Andriyani, A., Santosa, A. B., & Saryadi, W. (2022). Effectiveness of Microsoft Kaizala and Google Classroom towards students' mathematical communication skill and self-efficacy in learning statistics. *Bulletin of Applied Mathematics and Mathematics Education*, *2*(1), 33-46. https://doi.org/10.12928/bamme.v2i1.5523

Angraini, G., & Sriyati, S. (2019). Analisis kemampuan berpikir tingkat tinggi siswa SMAN Kelas X di kota Solok pada konten biologi [Analysis of high-level thinking skills of grade X senior high school students in Solok city on biology content]. *Journal of Education Informatic Technology and Science (JeITS)*, *1*(1), 114-124.

Bai, B., & Wang, J. (2023). The role of growth mindset, self-efficacy and intrinsic value in self-regulated learning and English language learning achievements. *Language Teaching Research*, *27*(1), 207-228. https://doi.org/10.1177/1362168820933190

Başaran, M., & Bay, E. (2023). The effect of project-based STEAM activities on the social and cognitive skills of preschool children. *Early Child Development and Care*, *193*(5), 679-697. https://doi.org/10.1080/03004430.2022.2146682

Becker, K. H., & Park, K. (2011). Integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A meta-analysis. *Journal of STEM Education: Innovations and Research*, *12*(5), 23-37.

Bertrand, M. G., & Namukasa, I. K. (2020). STEAM education: student learning and transferable skills. *Journal of Research in Innovative Teaching & Learning*, *13*(1), 43-56. https://doi.org/10.1108/JRIT-01-2020-0003

Boice, K. L., Jackson, J. R., Alemdar, M., Rao, A. E., Grossman, S., & Usselman, M. (2021). Supporting teachers on their STEAM journey: A collaborative STEAM teacher training program. *Education Sciences*, *11*(3), 105. https://doi.org/10.3390/educsci11030105

Cai, J. (2023). Evaluation of blended teaching in STEAM education using structural equation model questionnaire technology. *International Journal of Emerging Technologies in Learning (iJET)*, *18*(19), 72-83. https://doi.org/10.3991/ijet.v18i19.43873

Chang, C.-Y., Du, Z., Kuo, H.-C., & Chang, C.-C. (2023). Investigating the impact of design thinking-based STEAM PBL on students' creativity and computational thinking. *IEEE Transactions on Education*, *66*(6), 673-681. https://doi.org/10.1109/TE.2023.3297221

Chen, C.-C., & Huang, P.-H. (2023). The effects of STEAM-based mobile learning on learning achievement and cognitive load. *Interactive Learning Environments*, *31*(1), 100-116. https://doi.org/10.1080/10494820.2020.1761838

Chen, R. H. (2021). Fostering students' workplace communicative competence and collaborative mindset through an inquiry-based learning design. *Education Sciences*, *11*(1), 17. https://doi.org/10.3390/educsci11010017

Chistyakov, A. A., Zhdanov, S. P., Avdeeva, E. L., Dyadichenko, E. A., Kunitsyna, M. L., & Yagudina, R. I. (2023). Exploring the characteristics and effectiveness of project-based learning for science and STEAM education. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(5), em2256. https://doi.org/10.29333/ejmste/13128

Conradty, C., & Bogner, F. X. (2020). STEAM teaching professional development works: effects on students' creativity and motivation. *Smart learning environments*, *7*(1), 26. https://doi.org/10.1186/s40561-020-00132-9

Cunha, M. N., Figueiredo, J., Oliveira, I., & Mações, M. (2024). Motivating students for success: A review of new projects in teaching based on STEM education. *Economics: Time Realities*, *71*(1), 65-71. https://doi.org/10.15276/ETR.01.2024.8

Diego-Mantecon, J.-M., Prodromou, T., Lavicza, Z., Blanco, T. F., & Ortiz-Laso, Z. (2021). An attempt to evaluate STEAM project-based instruction from a school mathematics perspective. *ZDM – Mathematics Education*, *53*(5), 1137-1148. https://doi.org/10.1007/s11858-021-01303-9

Dostál, J., Děrda, R., Částková, P., Mrázek, M., Kubrický, J., Steingartner, W., Bučková, H., Janu, M., & Kronáč, J. (2022). Innovative Concept of STEAM Education at Primary Schools in the Czech Republic-Support for Implementation in School Practice. In *2022 IEEE 16th International Scientific Conference on Informatics (Informatics)*, Poprad, Slovakia (pp. 60-66). https://doi.org/10.1109/Informatics57926.2022.10083467

Duo-Terron, P., Hinojo-Lucena, F.-J., Moreno-Guerrero, A.-J., & López-Núñez, J.-A. (2022). STEAM in primary education. impact on linguistic and mathematical competences in a disadvantaged context. *Frontiers in Education*, *7*, 792656. https://doi.org/10.3389/feduc.2022.792656

Effendi, K. N. S., Zulkardi, Z., Putri, R. I. I., & Yaniawati, P. (2020). Reading text for school literacy movement in mathematics learning. *Jurnal Pendidikan Matematika*, *14*(2), 145-154. https://doi.org/10.22342/jpm.14.2.6731.145-154

Fauzan, A., Harisman, Y., Yerizon, Y., Suherman, S., Tasman, F., Nisa, S., Sumarwati, S., Hafizatunnisa, H., & Syaputra, H. (2024). Realistic mathematics education (RME) to improve literacy and numeracy skills of elementary school students based on teachers' experience. *Infinity Journal*, *13*(2), 301-316. https://doi.org/10.22460/infinity.v13i2.p301-316

Fisher, D., Yaniawati, P., & Kusumah, Y. S. (2017). The use of CORE model by metacognitive skill approach in developing characters junior high school students. *AIP Conference Proceedings*, *1868*(1), 050010. https://doi.org/10.1063/1.4995137

Gabriel, F., Buckley, S., & Barthakur, A. (2020). The impact of mathematics anxiety on self-regulated learning and mathematical literacy. *Australian Journal of Education*, *64*(3), 227-242. https://doi.org/10.1177/0004944120947881

Gellert, U., Jablonka, E., & Keitel, C. (2013). Mathematical literacy and common sense in mathematics education. In B. Atweh, H. Forgasz, & B. Nebres (Eds.), *Sociocultural research on mathematics education* (pp. 57-73). Routledge.

Hadiyanti, N. F. D., Hobri, H., Prihandoko, A. C., Susanto, S., Murtikusuma, R. P., Khasanah, N., & Maharani, P. (2021). Development of mathematics e-module with STEM-collaborative project based learning to improve mathematical literacy ability of vocational high school students. *Journal of Physics: Conference Series*, *1839*(1), 012031. https://doi.org/10.1088/1742-6596/1839/1/012031

Hardman, J. (2019). Towards a pedagogical model of teaching with ICTs for mathematics attainment in primary school: A review of studies 2008-2018. *Heliyon*, *5*(5), e01726. https://doi.org/10.1016/j.heliyon.2019.e01726

Harisman, Y., Noto, M. S., & Hidayat, W. (2021). Investigation of students' behavior in mathematical problem solving. *Infinity Journal*, *10*(2), 235-258. https://doi.org/10.22460/infinity.v10i2.p235-258

Herrero, A. C., Recio, T., Tolmos, P., & Vélez, M. P. (2023). From the STEAM engine to STEAM education: An experience with pre-service mathematics teachers. *Mathematics*, *11*(2), 473. https://doi.org/10.3390/math11020473

Herro, D., Quigley, C., Plank, H., Abimbade, O., & Owens, A. (2022). Instructional practices promoting computational thinking in STEAM elementary classrooms. *Journal of Digital Learning in Teacher Education*, *38*(4), 158-172. https://doi.org/10.1080/21532974.2022.2087125

Hsiao, P.-W., & Su, C.-H. (2021). A study on the impact of STEAM education for sustainable development courses and its effects on student motivation and learning. *Sustainability*, *13*(7), 3772. https://doi.org/10.3390/su13073772

Hsu, Y.-C. (2020). Exploring the learning motivation and effectiveness of applying virtual reality to high school mathematics. *Universal Journal of Educational Research*, *8*(2), 438-444. https://doi.org/10.13189/ujer.2020.080214

Indahwati, S. D., Rachmadiarti, F., & Hariyono, E. (2023). Integration of PJBL, STEAM, and learning tool development in improving students' critical thinking skills. *IJORER: International Journal of Recent Educational Research*, *4*(6), 808-818. https://doi.org/10.46245/ijorer.v4i6.434

Ishartono, N., Razak, R. b. A., Kholid, M. N., Arlinwibowo, J., & Afiyah, A. N. (2024). Integrating STEAM into flip flop model to improve students' understanding on

composition of functions during online learning. *Infinity Journal*, *13*(1), 45-60. https://doi.org/10.22460/infinity.v13i1.p45-60

Iyer, V., Naandheny, S., & Manjuri, D. (2023). A Review of Pedagogical Advancements in Mathematics Education for Future Engineers. In *2023 2nd International Conference on Advancements in Electrical, Electronics, Communication, Computing and Automation (ICAECA)*, Coimbatore, India (pp. 1-6). https://doi.org/10.1109/ICAECA56562.2023.10200980

Jesionkowska, J., Wild, F., & Deval, Y. (2020). Active learning augmented reality for STEAM education—A case study. *Education Sciences*, *10*(8), 198. https://doi.org/10.3390/educsci10080198

Kadir, D., Judijanto, L., Widodo, J., Sidik, E. A., Haq, M. S., & Santosa, T. A. (2023). The effect STEAM based discovery learning model on students thinking ability: Meta-analysis study. *Jurnal Penelitian Pendidikan IPA*, *9*(12), 1245-1253. https://doi.org/10.29303/jppipa.v9i12.5944

Kariadinata, R., Yaniawati, R. P., Juariah, J., Sugilar, H., & Muthmainah, A. (2019). Spatial thinking ability and mathematical character students through Cabri 3D with a scientific approach. *Journal of Physics: Conference Series*, *1402*(7), 077094. https://doi.org/10.1088/1742-6596/1402/7/077094

Khairani, C. P., & Mudjiran, M. (2022). Pengembangan modul bimbingan dan konseling untuk meningkatkan karakter tangguh siswa dalam belajar [Development of guidance and counseling modules to improve students' resilient character in learning]. *Jurnal Riset Tindakan Indonesia*, *7*(4), 642-650.

Kim, Y. E., Morton, B. G., Gregorio, J., Rosen, D. S., Edouard, K., & Vallett, R. (2019). Enabling creative collaboration for all levels of learning. *Proceedings of the National Academy of Sciences*, *116*(6), 1878-1885. https://doi.org/10.1073/pnas.1808678115

Körtesi, P., Simonka, Z., Szabo, Z. K., Guncaga, J., & Neag, R. (2022). Challenging examples of the wise use of computer tools for the sustainability of knowledge and developing active and innovative methods in STEAM and mathematics education. *Sustainability*, *14*(20), 12991. https://doi.org/10.3390/su142012991

Kozakli Ulger, T., Bozkurt, I., & Altun, M. (2022). Analyzing in-service teachers' process of mathematical literacy problem posing. *International Electronic Journal of Mathematics Education*, *17*(3), em0687. https://doi.org/10.29333/iejme/11985

Kurniawati, R. P., Gunawan, I., & Marlina, D. (2020). Mathematic literation abilities based on problem solving abilities in first class 4 of elementary school. In *2nd Early Childhood and Primary Childhood Education (ECPE 2020)*, (pp. 186-192). https://doi.org/10.2991/assehr.k.201112.033

Li, J., Luo, H., Zhao, L., Zhu, M., Ma, L., & Liao, X. (2022). Promoting STEAM education in primary school through cooperative teaching: A design-based research study. *Sustainability*, *14*(16), 10333. https://doi.org/10.3390/su141610333

Lin, C.-L., & Tsai, C.-Y. (2021). The effect of a pedagogical STEAM model on students' project competence and learning motivation. *Journal of Science Education and Technology*, *30*(1), 112-124. https://doi.org/10.1007/s10956-020-09885-x

Mahlow, C., & Hediger, A. (2021). Education as loosely coupled system of technology and pedagogy. *On Education: Journal for Research and Debate*, *4*(12), 1-11.

Murtiyasa, B., & Perwita, W. R. G. (2020). Analysis of mathematics literation ability of students in completing PISA-oriented mathematics problems with changes and relationships content. *Universal Journal of Educational Research*, *8*(7), 3160-3172. https://doi.org/10.13189/ujer.2020.080745

Nantschev, R., Feuerstein, E., González, R. T., Alonso, I. G., Hackl, W. O., Petridis, K., Triantafyllou, E., & Ammenwerth, E. (2020). Teaching approaches and educational technologies in teaching mathematics in higher education. *Education Sciences*, *10*(12), 354. https://doi.org/10.3390/educsci10120354

Ng, A. (2024). Empowering Malaysian early childhood practitioners' sustainable inclusive practices through the 'integrating and navigating Science, Technology, Engineering, Arts, and Mathematics'(inSTEAM) framework. *Eurasia Journal of Mathematics, Science and Technology Education*, *20*(11), em2531. https://doi.org/10.29333/ejmste/15579

Ní Shé, C., Ní Fhloinn, E., & Mac an Bhaird, C. (2023). Student engagement with technology-enhanced resources in mathematics in higher education: A review. *Mathematics*, *11*(3), 787. https://doi.org/10.3390/math11030787

Novita, R., & Herman, T. (2021). Digital technology in learning mathematical literacy, can it helpful? *Journal of Physics: Conference Series*, *1776*(1), 012027. https://doi.org/10.1088/1742-6596/1776/1/012027

Ozkan, G., & Umdu Topsakal, U. (2021). Investigating the effectiveness of STEAM education on students' conceptual understanding of force and energy topics. *Research in Science & Technological Education*, *39*(4), 441-460. https://doi.org/10.1080/02635143.2020.1769586

Pellegrini, M., Lake, C., Neitzel, A., & Slavin, R. E. (2021). Effective programs in elementary mathematics: A meta-analysis. *AERA Open*, *7*(1), 1-29. https://doi.org/10.1177/2332858420986211

Putri, A. S., Prasetyo, Z. K., Purwastuti, L. A., Prodjosantoso, A. K., & Putranta, H. (2023). Effectiveness of STEAM-based blended learning on students' critical and creative thinking skills. *International Journal of Evaluation and Research in Education (IJERE)*, *12*(1), 44-52. https://doi.org/10.11591/ijere.v12i1.22506

Quigley, C. F., Herro, D., Shekell, C., Cian, H., & Jacques, L. (2020). Connected learning in STEAM classrooms: opportunities for engaging youth in science and math classrooms. *International Journal of Science and Mathematics Education*, *18*(8), 1441-1463. https://doi.org/10.1007/s10763-019-10034-z

Rahmawati, Y., Taylor, E., Taylor, P. C., Ridwan, A., & Mardiah, A. (2022). Students' engagement in education as sustainability: Implementing an ethical dilemma-STEAM teaching model in chemistry learning. *Sustainability*, *14*(6), 3554. https://doi.org/10.3390/su14063554

Rodríguez-Nieto, C. A., & Alsina, Á. (2022). Networking between ethnomathematics, STEAM education, and the globalized approach to analyze mathematical connections in daily practices. *Eurasia Journal of Mathematics Science and Technology Education*, *18*(3), em2085. https://doi.org/10.29333/ejmste/11710

Setiawati, S., Herman, T., & Jupri, A. (2017). Investigating middle school students' difficulties in mathematical literacy problems level 1 and 2. *Journal of Physics:*

Conference Series, *909*(1), 012063. https://doi.org/10.1088/1742-6596/909/1/012063

Shi, A., Wang, Y., & Ding, N. (2022). The effect of game–based immersive virtual reality learning environment on learning outcomes: designing an intrinsic integrated educational game for pre–class learning. *Interactive Learning Environments*, *30*(4), 721-734. https://doi.org/10.1080/10494820.2019.1681467

Silawati, E. (2019). New media literacy in the context of early childhood education (An overview from Indonesian kindergarten future teachers). In *International Conference on Education, Social Sciences and Humanities*, (pp. 12-16).

Siregar, Y. E. Y., Rahmawati, Y., & Suyono, S. (2023). The impact of an integrated STEAM project delivered via mobile technology on the reasoning ability of elementary school students. *JOTSE: Journal of Technology and Science Education*, *13*(1), 410-428. https://doi.org/10.3926/jotse.1446

Stacey, K. (2015). The international assessment of mathematical literacy: PISA 2012 framework and items. In S. J. Cho (Ed.), *Selected Regular Lectures from the 12th International Congress on Mathematical Education* (pp. 771-790). Springer International Publishing. https://doi.org/10.1007/978-3-319-17187-6_43

Suganda, E., Latifah, S., Irwandani, Sari, P. M., Rahmayanti, H., Ichsan, I. Z., & Mehadi Rahman, M. (2021). STEAM and Environment on students' creative-thinking skills: A meta-analysis study. *Journal of Physics: Conference Series*, *1796*(1), 012101. https://doi.org/10.1088/1742-6596/1796/1/012101

Sukmawati, E., Imanah, N. D. N., & Rantauni, D. A. (2023). Implementation and challenges of project-based learning of STEAM in the university during the pandemic: A systematic literature review. *JINoP (Jurnal Inovasi Pembelajaran)*, *9*(1), 128-139. https://doi.org/10.22219/jinop.v9i1.25177

Supianti, I. I., Yaniawati, P., Osman, S. Z. M., Al-Tamar, J., & Lestari, N. (2022). Development of teaching materials for e-learning-based statistics materials oriented towards the mathematical literacy ability of vocational high school students. *Infinity Journal*, *11*(2), 237-254. https://doi.org/10.22460/infinity.v11i2.p237-254

Umbara, U., Prabawanto, S., & Jatisunda, M. G. (2023). Combination of mathematical literacy with ethnomathematics: How to perspective sundanese culture. *Infinity Journal*, *12*(2), 393-414. https://doi.org/10.22460/infinity.v12i2.p393-414

Wahba, F. A.-A., Tabieh, A. A., & Banat, S. Y. (2022). The power of STEAM activities in enhancing the level of metacognitive awareness of mathematics among students at the primary stage. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(11), em2185. https://doi.org/10.29333/ejmste/12562

Wijaya, T. T., Hidayat, W., Hermita, N., Alim, J. A., & Talib, C. A. (2024). Exploring contributing factors to PISA 2022 mathematics achievement: Insights from Indonesian teachers. *Infinity Journal*, *13*(1), 139-156. https://doi.org/10.22460/infinity.v13i1.p139-156

Witdiya, T., Supriadi, G., Supriatin, A., & Annovasho, J. (2023). The effect of STEAM learning on improving each indicator of students' creative thinking in physics learning. *Jurnal Ilmiah Pendidikan Fisika*, *7*(1), 42-50. https://doi.org/10.20527/jipf.v7i1.7158

Yaniawati, P., Fisher, D., Permadi, Y. D., & Yatim, S. A. M. (2023). Development of mobile-based digital learning materials in blended learning oriented to students' mathematical literacy. *International Journal of Information and Education Technology*, *13*(9), 1338-1347. https://doi.org/10.18178/ijiet.2023.13.9.1936

Yaniawati, P., & Indrawan, R. (2024). *Metode penelitian: Konsep, teknik, dan aplikasi* [Research methods: Concepts, techniques and applications]. Refika Aditama.

Yeager, D. S., & Dweck, C. S. (2020). What can be learned from growth mindset controversies? *American psychologist*, *75*(9), 1269-1284. https://doi.org/10.1037/amp0000794

Yeager, D. S., Hanselman, P., Walton, G. M., Murray, J. S., Crosnoe, R., Muller, C., Tipton, E., Schneider, B., Hulleman, C. S., Hinojosa, C. P., Paunesku, D., Romero, C., Flint, K., Roberts, A., Trott, J., Iachan, R., Buontempo, J., Yang, S. M., Carvalho, C. M., . . . Dweck, C. S. (2019). A national experiment reveals where a growth mindset improves achievement. *Nature*, *573*(7774), 364-369. https://doi.org/10.1038/s41586-019-1466-y

Zhang, J., Wang, Y., Leong, C., Mao, Y., & Yuan, Z. (2024). Bridging stories and science: An fNIRS-based hyperscanning investigation into child learning in STEM. *NeuroImage*, *285*, 120486. https://doi.org/10.1016/j.neuroimage.2023.120486

Ziatdinov, R., & Valles, J. R. (2022). Synthesis of modeling, visualization, and programming in GeoGebra as an effective approach for teaching and learning STEM topics. *Mathematics*, *10*(3), 398. https://doi.org/10.3390/math10030398