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Developing engaging STEAM-geometry activities: Fostering mathematical creativity through the engineering design process using Indonesian cuisine context

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Abstract

Enhancing mathematical creativity requires more learning activities that foster creative thinking. However, teachers need more resources and activities to nurture students' creativity in mathematics effectively. Therefore, this study aimed to design STEAM-based geometry activities using the Engineering Design Process (EDP) to explore how such projects can enhance students' mathematical creativity. In this study, creativity focuses on how students use geometric principles to design Wingko Babat as an Indonesian cuisine, making culturally meaningful connections and solving design challenges. The study involved research and development using the analysis, design, development, implementation, and evaluation (ADDIE) model, continuing with a descriptive qualitative approach. The activities designed for the STEAM-Geometry projects allow students to think creatively and elaborate on the engineering design process. Through expert reviews that involved multiple educators, the design activities on the STEAM-Geometry project are reliable and valid. The findings show that the EDP on Geometry project enables students to think creatively. The findings imply that teaching geometry can develop the students' mathematical creativity through the engineering design process in STEAM activities. Furthermore, it indicates that the design activities encompass more than just understanding geometry; they also nurture creativity by applying STEAM principles in the engineering design process. Integrating STEAM principles within culturally meaningful, geometry-based tasks enhances students' critical thinking, creativity, collaboration, and real-world problem-solving skills, preparing them to tackle complex challenges beyond the scope of mathematics.

Keywords:
Design activities, Engineering design process, Mathematical creativity, STEAM, STEAM-geometry

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1. INTRODUCTION

Indonesian education has been criticized for emphasizing rote memorization and procedural understanding over problem-solving and critical-thinking skills (Handican et al., 2023; Ilyas, 2017; Mbato, 2019). This approach may hinder students' ability to think creatively in mathematics and apply their knowledge to real-world situations. Moreover, traditional teaching methods often prioritize the correct answer and standardized procedures rather than encouraging students to explore multiple solutions or think creatively in mathematics (Cardellini, 2006; Nguyen et al., 2020; Silver et al., 2005; Stein & Lane, 1996). For example, younger students or those with kinesthetic and visual learning preferences may experience a greater hindrance to creativity, especially in settings that prioritize rote memorization over exploratory project-based learning. It can lead to a limited understanding of mathematics and inhibit the development of mathematical creativity. In some classrooms, instruction tends to be teacher-centred, with limited opportunities for students to engage in active problem-solving and creative thinking (Carpenter & Peterson, 1988; Maynes, 2012; Seifert & Simmons, 1997). Students may have fewer chances to express their mathematical ideas, explore alternative approaches, and develop their creativity. Mathematical creativity thrives when students can connect mathematical concepts to real-world contexts (Švecová et al., 2014; Voica & Singer, 2012). However, there may be limited emphasis on applying mathematical knowledge to practical situations, which can impede students' ability to think creatively and see the relevance of mathematics in their daily lives.

Mathematical creativity is paramount in 21st-century learning (Kozlowski & Si, 2019; Pehkonen, 1997; Suherman et al., 2021). It equips students with the skills and mindset necessary to navigate complex problems, think critically and innovatively, make interdisciplinary connections, adapt to new situations, and excel in various career paths (Nadjafikhah et al., 2012; Riling, 2020; Silver, 1997). By fostering mathematical creativity, educators prepare students to become adaptable, creative, and innovative individuals who can thrive in the dynamic and interconnected world of the 21st century. Mathematical creativity enables students to approach problems from different angles, think outside the box, and generate innovative solutions (Grégoire, 2016; Haylock, 1987; Silver, 1997). It encourages them to explore alternative approaches, consider multiple perspectives, and adapt their thinking to various contexts, fostering a mindset of innovation and problem-solving. However, acknowledging the potential challenges could be mitigated by identifying strategies to support students such as offering scaffolding, examples of alternative approaches, and gradual shifts from structured to open-ended tasks which would provide a more balanced perspective on implementing these activities. Moreover, mathematical creativity promotes critical thinking and analytical skills (Silver, 1997; Sriraman, 2009). It allows students to analyze and evaluate mathematical concepts, relationships, and patterns. By engaging in creative mathematical activities, students learn to identify patterns, make connections, and apply logical reasoning. These skills are essential in evaluating information, making informed decisions, and navigating the complexities of the 21st century (Gretter & Yadav, 2016; Szabo et al., 2020; Toheri et al., 2019).

The 21st century is characterized by the increasing interconnectedness of various disciplines. Mathematical creativity enables students to make connections between mathematics and other subjects such as science, technology, engineering, arts, and even social sciences (Freiman & Tassell, 2018; Kattou et al., 2013; Leikin & Pitta-Pantazi, 2013; Munakata & Vaidya, 2012; Silver, 1997; Sriraman, 2009; Švecová et al., 2014). It allows them to apply mathematical concepts and methods in diverse contexts, contributing to a more holistic understanding of the world and fostering interdisciplinary problem-solving.

The integration of arts into science, technology, engineering, and mathematics (STEM) is supposed to reshape scientific education and humanities education, especially when further supported by problem-solving integration within trans-disciplinary frameworks (Fenyvesi, 2015; Salmi et al., 2023). The integration of STEAM disciplines in education has gained prominence in recent years (Bahrum et al., 2017; Liao, 2016; Ng et al., 2022; Perignat & Katz-Buonincontro, 2019; Pramasdyahsari et al., 2023). By integrating these disciplines, students are encouraged to approach challenges with a multidisciplinary mindset STEAM education provides students with a holistic approach to learning. It has gained significant recognition for its ability to foster critical thinking, creativity, and problem-solving skills in students (Aguilera & Ortiz-Revilla, 2021; Hanif et al., 2019; Hebebci & Usta, 2022; Pramasdyahsari et al., 2023; Zakeri et al., 2023). One of the key strategies has been to incorporate artistic, practical, and creative elements into mathematics learning and teaching techniques, particularly when compared to other fields of study and cultural traditions. Factors such as differing educational systems, cultural attitudes toward art and science, and resource availability can significantly influence the success of STEAM initiatives, raising questions about how these elements are perceived and implemented across various settings. However, few studies have sufficient evidence to support these real-world observations. As a result, the growing STEAM movement and activities urgently require pertinent and trustworthy research.

Within the realm of STEAM, geometry projects offer an excellent platform to explore the fascinating connections between mathematics, art, and design (Henriksen, 2017; Montero, 2018; Ng, 2017; Parhusip et al., 2023; Spikol & Eliasson, 2010). Research has demonstrated the positive impact of STEAM integration on geometry learning outcomes. Studies show that engaging students in hands-on design activities that blend mathematical concepts with artistic expression leads to a deeper understanding and appreciation of geometry (Brijlall et al., 2006; Ernest & Nemirovsky, 2016; Jacobson & Lehrer, 2000; Joglar Prieto et al., 2014; Parhusip et al., 2023). Such immersive experiences not only enhance spatial reasoning skills but also promote problem-solving abilities, as students learn to apply geometric principles to real-world design challenges (Brijlall et al., 2006; Chandler & Ward, 2019; Olkun, 2003).

Several studies have shown the impact of integrating STEAM into students' learning outcomes (Hsiao & Su, 2021; Kang, 2019; Lin & Tsai, 2021; Ortiz-Revilla et al., 2021; Ozkan & Umdu Topsakal, 2021). The integration of STEAM disciplines, including geometry, has shown a positive impact on students' learning outcomes. To achieve positive outcomes in STEAM integration, several specific activities and teaching strategies can be employed. Project-based learning by reinforcing geometric concepts and hands-on activities, such as building models allow students to apply these principles tangibly. Collaborative group work encourages peer learning, while structured reflection and feedback sessions foster critical thinking and iterative improvement. Additionally, interdisciplinary lessons that combine art and mathematics, such as creating geometric art or patterns, help students recognize the relevance of geometry in everyday contexts. Together, these strategies engage students and enhance their understanding of geometric concepts within a STEAM framework. It has enhanced their understanding of geometric concepts, spatial visualization skills, and motivation to learn. Several studies have investigated the effects of STEAM integration on geometry education, highlighting its benefits in enhancing students' understanding and engagement in the subject (Kang, 2019; Kim & Park, 2012; Ozkan & Umdu Topsakal, 2021; Parhusip et al., 2023; Sutama et al., 2020). By providing hands-on, creative, and interdisciplinary learning experiences, STEAM integration in geometry education promotes a holistic approach to learning that prepares students for the challenges of the 21st century.

One study conducted by Ozkan and Umdu Topsakal (2021), examined the impact of a STEAM-based geometry curriculum on middle school students' learning outcomes. The findings revealed that students who participated in the STEAM program showed significant improvements in their geometry achievement compared to those in traditional math classes. The hands-on nature of the STEAM activities, which involved designing and creating geometric structures, helped students develop a deeper understanding of geometric concepts and their real-world applications. Another study by Goldsmith et al. (2016), investigated the effects of integrating art and geometry in a STEAM project on students' spatial visualization skills. The results indicated that students who engaged in the STEAM project demonstrated enhanced spatial visualization abilities compared to those in a traditional geometry class. The integration of art elements, such as drawing and creating visual representations of geometric concepts, helped students develop spatial reasoning skills and a better understanding of geometric relationships. Furthermore, STEAM integration in geometry education has been found to foster student motivation and engagement. A study by Ariba and Luneta (2018), explored the impact of incorporating artistic activities into geometry lessons. The findings revealed that students who participated in art-integrated geometry lessons exhibited higher levels of motivation and interest in the subject compared to those in traditional math classes. The combination of artistic expression and geometric concepts sparked students' curiosity and creativity, making geometry more enjoyable and meaningful. However, others may find these elements distracting or unrelated to their learning objectives, potentially hindering their focus and performance. By considering this diversity, educators can gain a more nuanced understanding of the varying impacts that artistic integration can have on students. This perspective encourages the development of more tailored STEAM activities that cater to different learning needs, ensuring that all students can engage meaningfully with the material and achieve positive learning outcomes. Ultimately, this acknowledgment fosters a more inclusive educational environment that values individual differences and maximizes the effectiveness of STEAM education.

The many ways that engineering design can improve students' aptitudes and dispositions to tackle challenging real-world problems have drawn significant attention in the literature (Cunningham & Hester, 2007; Diefes-dux et al., 2008; English et al., 2013; Mehalik et al., 2008; Moore et al., 2014; Purzer et al., 2014). Engineering design enables students to understand that there are numerous solutions to complex problems, multiple tools and representations. It can be used to create a desired outcome, and it is acceptable for initial designs to "fail" (Lachapelle & Cunningham, 2014).

Traditional learning methods often emphasize rote memorization and standardized testing, which can hinder creative mathematical thinking and limit real-world application. These approaches typically focus on individual work, providing little opportunity for collaboration or exploration of diverse problem-solving strategies. In contrast, the presented STEAM integration model addresses these shortcomings by promoting project-based learning, hands-on activities, and collaboration. This approach encourages students to engage with mathematical concepts in creative and culturally relevant contexts, fostering deeper understanding and critical thinking skills while overcoming the limitations of traditional methods.

One captivating way to introduce students to the STEAM approach is through the EDP (Dang Ut et al., 2022). However, there is a limitation on research that designs activity STEAM-based through geometry projects that particularly focus on stimulating students' mathematical creativity. Whereas, the research may contribute to offering the teaching practice with the possibility to improve mathematical creativity. Therefore, the study aims to design activities STEAM-based on geometry projects through the EDP and describe how the EDP on Geometry projects could foster students' mathematical creativity.

2. METHOD

The study employed the research and development (R & D) approach since the purpose was to develop a valid and practical instrument test of mathematical literacy based on the integration of STEM-PjBL aspects. The research procedures involved the ADDIE model (Creswell, 2014). The ADDIE process is a systematic instructional design model that can be applied to designing activities for a STEAM geometry project with a focus on fostering mathematical creative thinking. The problem "Wingko Babat Rainbow" was provided to students as a problem from daily life. The Wingko Babat rainbow is a geometry project activity that involves local wisdom. It was expected of students that they could identify the issue, research it, and come up with a solution in their minds. The students worked on a group project based on the information from the previous meeting, specifically the "Wingko Babat Rainbow" project, in the meeting that followed. To complete their making projects, students must be able to plan and design prototypes. Students could test their project once it was finished, and the evaluation of the feedback would be included in the product outcomes presentation. Students could therefore use that project to better the one they would create next. The stages mentioned above were modified for EDP. The data were collected from group worksheets and analyzed qualitatively by identifying recurring themes. This approach allowed for insights into common patterns, student understanding, and areas for improvement within the projects.

3. RESULTS AND DISCUSSION

3.1. Results

The design activities STEAM on geometry project involves the ADDIE model. The ADDIE process is a systematic instructional design model that can be applied to designing activities for a STEAM geometry project with a focus on fostering mathematical creative thinking. The results of each stage are described as the following procedures.

3.1.1. Analysis of Learning Environment

The information about the students and the classroom setting was acquired during the analysis stage. The factors that have been examined include understanding the students' previous knowledge, mathematical ability, and level of creative thinking. After that, finding out about students' interests and their preferred learning methods comes next. At this point, the available resources, time constraints, and any specific geometry-related curriculum requirements were taken into account. This analysis provides the foundation for creating learning activities that meet the needs of the learners and promote mathematical creativity. Understanding students’ interests and creative thinking levels could shape geometry-related tasks by integrating elements from Indonesian cuisine, such as wingko babat, a traditional coconut-based snack. In this study, the tasks involve students’ interest in cultural foods of the circular and layered geometry of wingko babat. Establishing this link between student interests in wingko babat and the design of geometry tasks would not only enhance relevance but also provide a culturally meaningful context for exploring geometric principles.

3.1.2. Designing the Project

The designed phase established the learning objectives and outcomes that correspond to geometry concepts and creative thinking abilities. In this stage, the scope of activities was carefully chosen and organized to ensure that students had the opportunity to explore and apply geometric concepts in new ways. To encourage interdisciplinary connections, various aspects of STEAM disciplines were incorporated. Additionally, teaching techniques and approaches were selected to stimulate creativity, such as the students working on a group project to solve open-ended problems, through hands-on experience. The engineering design process procedures were developed to assess both creative thinking and mathematical understanding.

3.1.3. Development of the Prototype

During the development phase, actual activities and materials for the STEAM geometry project were created. Furthermore, hands-on tasks, problem-solving scenarios, and design challenges that require students to apply geometric concepts in unique and creative ways were developed. After that, the necessary resources, such as manipulatives, technology tools, and art supplies were prepared to support the activities. The activities are appropriately scaffolded to support learners with different abilities and provide clear instructions to guide their exploration and thinking. In this study, the manipulatives involve geometric shapes and the application of a geometry calculator which fosters critical thinking at circle material (Astutik et al., 2024).

Expert validation was conducted to determine the validity of the implemented activity. Table 1 shows the summary of the average evaluation aspect including learning, skills, thinking skills, STEAM activities and relevance as assessed by the expert validator. It indicates that the designed activity is valid based on the average evaluation aspects.

Table 1. Validation result of learning, skills, thinking skills, STEAM activities, and relevance

No	Evaluation Aspect	1st Expert Validator	2nd Expert Validator	3rd Expert Validator	Average Score
1.	Learning	80%	95%	95%	90%
2.	Skills	88%	84%	96%	89%
3.	Thinking Skills	80%	83%	83%	82%
4.	STEAM Activities	80%	80%	100%	87%
5.	Relevance	80%	85%	100%	88%

3.1.4. Implementation of the Product

In the implementation phase, the activities and support provided to students as they engage in mathematical creative thinking were facilitated. The researcher introduced the activities, explained the objectives, and guided students through the process. Through this activity, collaboration and discussion among students are encouraged to promote idea-sharing and critical thinking. This stage also provides feedback and guidance to help students overcome challenges and refine their creative solutions. It fosters a supportive and inclusive learning environment that values and encourages diverse perspectives and approaches to problem-solving.

Throughout the qualitative descriptive procedure, maintain a close connection to the data collected from the students. This approach aims to provide a rich and detailed account of the engineering design process, capturing the essence of the experiences, challenges, and creative solutions. The findings can be used to inform future improvements in teaching and learning approaches, curriculum development, and the integration of engineering design processes in geometry projects. When conducting a qualitative descriptive procedure to elaborate on students' engineering design process in a geometry project, the researchers follow these steps: data collection, data analysis, data interpretation and elaboration; and synthesis and reporting.

In the data collection stage, the researchers select a sample of students who have participated in the geometry project. After that, data through observations, interviews, or written reflections from the students were collected. During the project implementation, open-ended questions were asked to encourage students to provide detailed descriptions of their engineering design process. The data from students were organized in the data analysis procedures, and key themes and patterns related to the students' engineering design process were identified. It includes the steps they took, the challenges they encountered, and the strategies they used to overcome those challenges. After that, the data were coded based on the identified themes and patterns. Lastly, create categories or subcategories to organize the coded data.

In the data interpretation and elaboration, the coded data and categories/ subcategories were examined to gain a deeper understanding of the students' engineering design process. The descriptions provided by the students to identify commonalities, differences, and unique aspects of their approaches were analyzed. Then, the students' experiences and specific examples that illustrate their engineering design process were elaborated. This stage provides detailed descriptions and narratives that capture the students' decision-making, problem-solving, collaboration, and creative thinking throughout the geometry project.

In the synthesis and reporting stage, the findings were synthesized from the data analysis and interpretation. Then, the key aspects of the students' engineering design process, including the steps they took, the strategies they used, and the impact of their design decisions on the geometry project were summarized. Figure 1 illustrates the product of each group solving the problem related to the Wingko Babat rainbow.

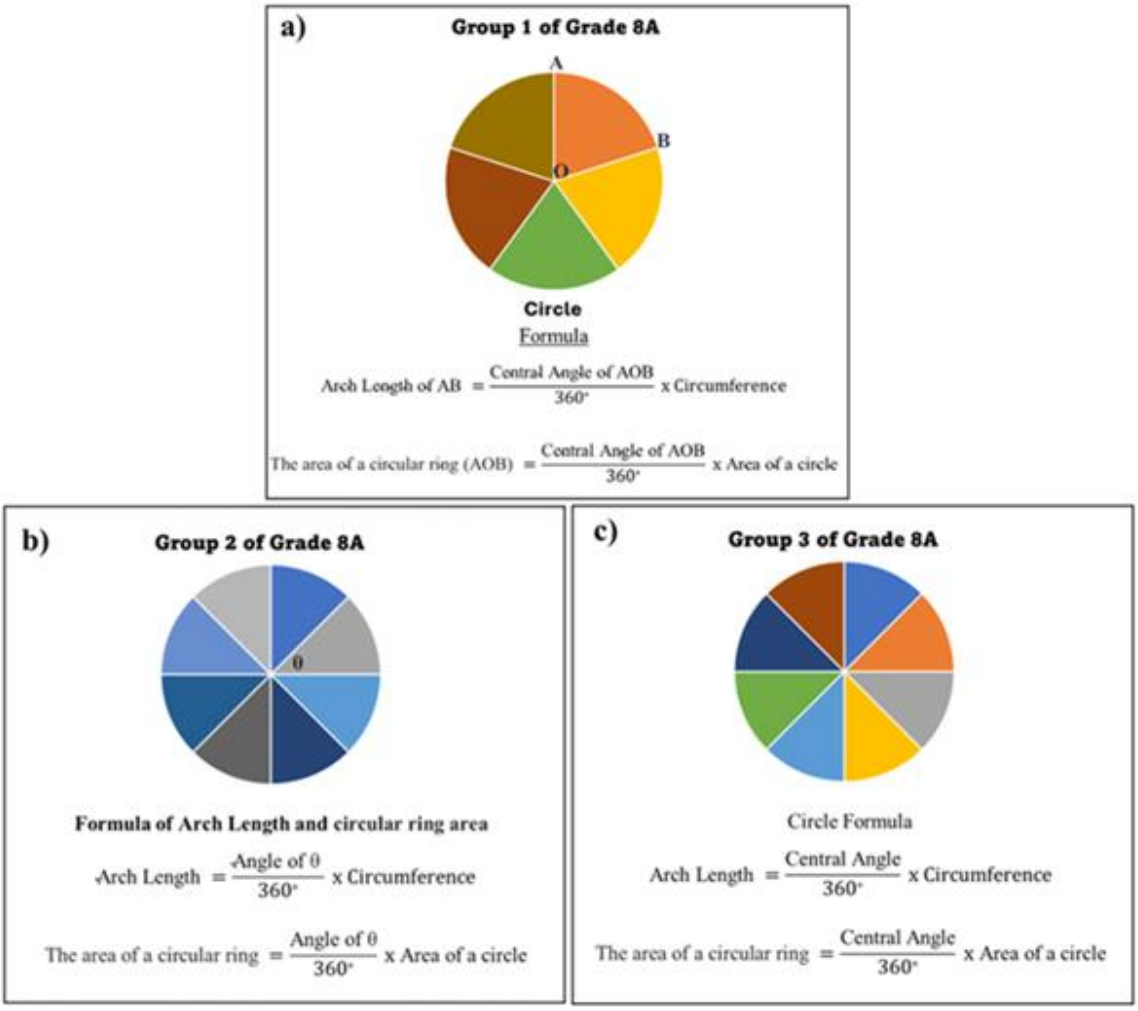
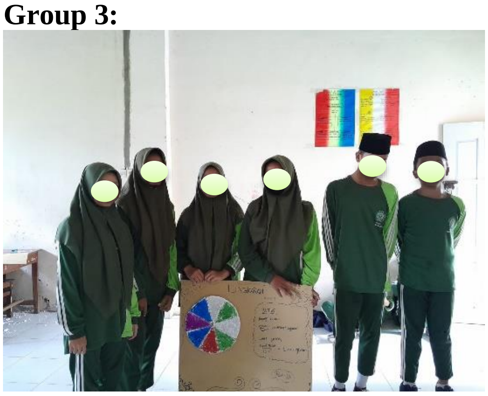


Figure 1. Product of the geometry projects of Wingko Babat rainbow: (a) Group 1; (b) Group 2; and (c) Group 3 in the Grade 8

The Engineering Design Process shows the stages of identification problem, possible solutions, sources of information, draft solution, manufacturing process, trial, revision, and communication as presented in Table 2.

Table 2. Analysis of engineering design process

Stages	Excerpt or Results	Analysis
Identification Problem	*Group 1:* Mrs. Ida gets an order *Wingko Babat* rainbow circle shaped which crop into 5-8 parts. *Group 2:* a *wingko* tripe rainbow-shaped circle to be shared into 5-8 parts. Group 3: Cutting circle into 5-8 parts.	Students can identify the problem.
Possible solutions and sources of information	*How did you finish the problem and where did you get the solution idea from?* Answer: *Group 1:* Our group will share like example in the given e-book. *Group 2:* We will share *Wingko Babat* rainbow-like pizza slice. *Group 3:* We will share *Wingko Babat* rainbow-like mille crepes.	Students can look for information from various sources such as through e-books that have given, mille crepes and pizza.
Draft solution	*After discussing various types of settlement with your group, write down what plan are you going to do to solve the problem.* Answer: *Group 1*: Our group will split it into 5 parts, then we will measure the corner using the provided bow ***(implementation of Engineering)*** *Group 2:* Our group will split it into 8 parts with the method shared into 2 parts, then 1 part that has been cut shared into 2 parts again, so get 8 parts. ***(Implementation of Science and Mathematics)*** *Group 3:* Our group will split it into 8 parts with the method shared into 2 parts, then 1 part that has been cut shared into 2 parts again, so get 8 parts. ***(Implementation of Science and Mathematics)***	Students can create the design to solve the problem.
Manufacturing process	Write it down in a coherent procedure of your project to solve the problem. Answer: Group 1: After dividing, we will colour the parts that have been cut one by one. Group 2: After dividing, we will colour the parts that have been cut one by one. Group 3: After dividing, we will colour the parts that have been cut one by one.	Students do an Art activity as a part of solving the problem.
Trial	What are the following procedures after the manufacturing process has been done?	Every group finishes the project with ok, next every group must count wide sharp, and long arc

Stages	Excerpt or Results	Analysis
	Answer: All groups answer the same idea that they count Group 1: We have to count corner circles especially first, so you can count wide sharp, and long bows. Group 2: We have to count corner circles especially first, so you can count wide sharp, and long bows. Group 3: We have to count corner circles especially first, so you can count wide sharp, and long bows.	using an application *geometry calculator*.
Revision (if any)	How if, your plan does not work to solve your problem?	Each group does not revise their project since they believe that their project has been solved.
Communication	**Group 1:**  **Group 2:**  **Group 3:** 	Each group presents the results of the projects that they have made communicatively and collaboratively.

3.1.5. Evaluation

In the evaluation phase, both the mathematical understanding and the creative thinking skills of the students are assessed. The evaluation stage was conducted by considering the quality of student solutions that are demonstrated through activities that foster mathematical creative thinking, their ability to make connections across disciplines, and their levels of engagement and enthusiasm. Feedback is collected from students and reflections are made on the strengths and areas for improvement of the activities. This information is used to revise and refine the activities for future implementations. In the evaluation phase of the STEAM geometry project, it is crucial to assess both the students mathematical understanding and their creative thinking skills. There are some strategies to evaluate the effectiveness of the activities in fostering mathematical creative thinking: (1) Evaluate students' solutions to geometry problems or design challenges for creativity, innovative approaches, and unique problem-solving strategies. Assess their integration of geometry concepts into solutions and the application of critical thinking skills to solve complex problems; (2) Assess students' ability to connect geometry with other STEAM disciplines, looking for evidence of integration with science, technology, engineering, and arts in their projects. Evaluate their understanding of how geometry relates to real-world applications and their ability to apply geometric concepts in interdisciplinary contexts; (3) Observe students' levels of engagement and enthusiasm throughout the project. Determine if they actively participate in discussions and activities, showing curiosity and excitement. Use their level of engagement as an indicator of interest and investment in the project, often associated with higher levels of creativity and critical thinking.

3.2. Discussion

The results of the geometry project “Wingko Babat rainbow” offer students the opportunity to think creatively in solving problems. Each student working on the group project has the chance to develop their creative thinking, critical thinking, and problem-solving skills. The project fostered creativity and problem-solving by requiring students to design structures inspired by wingko babat, apply geometric concepts to real-world contexts, and work collaboratively on culturally relevant tasks. For example, students might have worked in teams to explore the circular and layered forms of wingko babat, brainstorming ways to represent these shapes in packaging or display models. Such activities encouraged them to think creatively about geometry, collaborate on shared ideas, and apply mathematical principles in innovative, culturally meaningful ways. This is consistent with previous research, which has shown that geometry projects provide an excellent platform for exploring the fascinating connections between mathematics, art, and design (Henriksen, 2017; Montero, 2018; Ng, 2017; Parhusip et al., 2023; Spikol & Eliasson, 2010). The results demonstrate that the hands-on design activities of the Wingko Babat rainbow project can also integrate mathematical concepts with artistic expression. This leads to a deeper understanding and appreciation of geometry as supported by previous research (Brijlall et al., 2006; Ernest & Nemirovsky, 2016; Jacobson & Lehrer, 2000; Joglar Prieto et al., 2014; Parhusip et al., 2023). The learning outcomes of students have demonstrated a positive impact from the integration of STEAM disciplines, including geometry. Their knowledge of geometric ideas, aptitude for spatial visualization, and eagerness to learn have all improved as a result. Variations likely occurred based on factors such as prior knowledge, learning styles, and engagement levels; for instance, students with a strong initial interest in visual-spatial tasks may have shown greater improvements, while others may have benefited differently or required additional support to reach similar outcomes. Acknowledging these variations would provide a more comprehensive understanding of the impact across diverse learner profiles. Examining how different learners responded to STEAM integration reveals the varied impacts on students with different backgrounds and learning styles. For instance, visual learners may have engaged more deeply with the geometry tasks, while hands-on activities may have benefited kinesthetic learners. Some students with strong prior knowledge in math might have advanced quickly, whereas those less confident may have required additional support. Understanding these diverse responses provides valuable insights into customizing STEAM approaches to better meet individual learning needs.

The engineering design process can significantly contribute to the development of mathematical creative thinking. The EDP is inherently about solving problems that require creativity and critical thinking, which are also essential components of mathematical creative thinking. By engaging in engineering design challenges, students are encouraged to approach problems from different angles and come up with innovative solutions. When students engage in EDP, they often need to apply mathematical concepts to create and analyze their designs. This practical application of mathematics helps students see the relevance and utility of mathematical concepts, making them more likely to engage with and remember them.

Moreover, the EDP often involves integrating knowledge from various disciplines, including mathematics, physics, and sometimes even art and design. This interdisciplinary approach encourages students to see the connections between different subjects and fosters a holistic understanding of how math can be applied in real-world contexts. This is in line with previous research that reveals that design can improve students' aptitudes and dispositions to tackle challenging real-world problems, which have drawn significant attention in the literature (Cunningham & Hester, 2007; Diefes-dux et al., 2008; English et al., 2013; Mehalik et al., 2008; Moore et al., 2014; Purzer et al., 2014). The EDP encourages creativity and innovation which aligns closely with mathematical creative thinking, involving approaching problems with a fresh perspective and finding unique solutions. Therefore, it encourages students to think outside the box in their design projects and can transfer over to their approach to mathematical problems.

The EDP is iterative, meaning it involves creating, testing, evaluating, and refining solutions. This iterative approach is also relevant in mathematics, where students may need to try different approaches, make adjustments, and refine their solutions. It helps foster a growth mindset and resilience in the face of mathematical challenges. Moreover, it involves solving practical, real-world problems. This contextualization can make mathematical concepts more meaningful and engaging for students. They can see how math is used to address real challenges, which can motivate them to approach mathematical problems with a sense of purpose.

Incorporating the engineering design process into mathematics education can be a powerful way to enhance mathematical creative thinking (Vistara et al., 2022). It provides students with opportunities to apply mathematical concepts in practical, meaningful ways, fostering a deeper understanding of the subject and promoting creativity, critical thinking, and problem-solving skills.

Furthermore, thematic analysis encompasses the identification, examination, and communication of patterns or themes within a dataset (Clarke & Braun, 2017; Lochmiller, 2021). In the context of formulating activities centred on STEAM-Geometry to cultivate mathematical creativity via the engineering design process, a thematic analysis unfolds as seen in Table 3.

Table 3. Thematic analysis of STEAM-geometry activity in cultivating mathematical creativity

No	Theme	Analysis
1	Integration of STEAM Disciplines	The activities seamlessly combine science, technology, engineering, arts, and mathematics (STEAM) disciplines, providing a comprehensive learning experience. These design activities require a deep understanding of geometric concepts while incorporating engineering principles. Additionally, students are allowed to explore the artistic aspects of geometry by incorporating artistic elements to enhance their creative expressions.
2	Real-World Application	An example of this is the design activity of *Wingko Babat* Rainbow, which highlight the practical application of geometry and mathematics through real-world engineering challenges. It creates activities that present students with tangible problems that require geometric solutions, thus promoting critical thinking. Furthermore, it establishes connections between the activities and real engineering applications, fostering an appreciation for how geometry is used in various fields, such as the context of preparing traditional food for a specific region in Indonesia.
3	Creativity in Design	This activity not only encourages creativity by integrating design thinking but also stimulates innovative solutions to geometric challenges. The design activities include open-ended elements, allowing students to explore different solutions and express their creativity. Additionally, the incorporation of phases for building physical prototypes encourages the hands-on application of geometric concepts. An example of this is the design activity of *Wingko Babat* Rainbow, which highlight the practical application of geometry and mathematics through real-world engineering challenges. It creates activities that present students with tangible problems that require geometric solutions, thus promoting critical thinking. Furthermore, it establishes connections between the activities and real engineering applications, fostering an appreciation for how geometry is used in various fields, such as the context of preparing traditional food for a specific region in Indonesia.
4	Collaborative Learning	The activity promotes collaboration among students, urging them to work together in addressing complex geometric problems within the engineering design process. These design activities require teamwork, fostering collaborative approaches to problem-solving

No	Theme	Analysis
		and communication. Furthermore, the inclusion of peer review sessions motivates students to evaluate and improve each other's geometric designs.
5	Reflection and Iteration	Within the framework of the engineering design process, students integrate reflection and iteration as essential components of the learning journey, emphasizing the importance of continuous improvement. Students keep reflective journals to document their thoughts, challenges encountered, and insights gained during the design process. Additionally, students are encouraged to refine and iterate their designs based on feedback and self-reflection, reinforcing the significance of ongoing improvement.

Based on Table 3, the thematic analysis reveals several key aspects of the integration of STEAM disciplines in educational activities. First, the activities seamlessly combine science, technology, engineering, arts, and mathematics (STEAM), providing a comprehensive learning experience that requires a deep understanding of geometric concepts while incorporating engineering principles. Students are encouraged to explore the artistic aspects of geometry, enhancing their creative expression. An example of this integration is the design activity of Wingko Babat Rainbow, which highlights the practical application of geometry through real-world engineering challenges. This activity presents tangible problems that necessitate geometric solutions, fostering critical thinking and illustrating how geometry is used in various fields, particularly in the context of preparing traditional food in Indonesia.

Additionally, the activities stimulate creativity by incorporating design thinking, allowing for open-ended exploration of different solutions and innovative responses to geometric challenges. The hands-on application of geometric concepts is emphasized through phases for building physical prototypes. Collaborative learning is also promoted, as students work together to tackle complex geometric problems within the engineering design process, fostering teamwork and communication. Peer review sessions motivate students to evaluate and enhance each other's designs. Finally, reflection and iteration are integral to the learning journey, with students keeping reflective journals to document their thoughts, challenges, and insights. They are encouraged to refine their designs based on feedback and self-reflection, reinforcing the importance of continuous improvement throughout the process. Overall, this analysis highlights how the integration of STEAM disciplines enriches the learning experience and cultivates essential skills in students.

These thematic analyses not only enhance students' understanding of geometry through design activities but also foster creativity by applying STEAM principles in the engineering design process. Comparing these findings with previous studies shows consistent positive impacts of STEAM integration on student engagement and learning outcomes, particularly in areas like spatial visualization, creative problem-solving, and motivation (Conradty & Bogner, 2020; Cooke, 2022; Hsiao & Su, 2021; Lage-Gómez & Ros, 2023). Prior research has similarly found that interdisciplinary approaches, especially those combining art and mathematics, enhance students' conceptual understanding and make abstract concepts more accessible (Breda et al., 2023; Smith, 2021). However, this study adds a culturally relevant element using Indonesian cuisine as a context that previous studies may lack, which appears to further enrich students' engagement by connecting learning to familiar, real-world experiences. This culturally specific approach could suggest a unique advantage over more generalized STEAM interventions, potentially supporting higher engagement and deeper understanding in contexts that are personally meaningful to students.

Based on the discussion results, several recommendations can enhance the effectiveness of STEAM integration in geometry learning. First, incorporating culturally relevant elements, such as Indonesian cuisine, connects abstract concepts to students' lived experiences, making learning more engaging and meaningful. Future curriculum designs should include cultural references to boost student interest and motivation. Additionally, since students showed varied responses to STEAM activities, it is essential to differentiate instruction to accommodate diverse learning styles, prior knowledge, and engagement levels. Providing additional support for students with less confidence in math or offering varied tasks tailored to visual, auditory, and kinesthetic learners can maximize learning benefits. Encouraging collaborative learning is also recommended, as teamwork fosters problem-solving skills and allows students to learn from each other's strengths. Finally, structured reflection opportunities enable students to evaluate their work and understand how feedback can guide improvement, reinforcing the engineering design process and deepening their learning experience. These recommendations would help educators refine STEAM-based geometry instruction to be more inclusive, engaging, and relevant for diverse learners.

4. CONCLUSION

The results show that the designed activities on STEAM-Geometry have been developed using the model of ADDIE and are valid. The STEAM-Geometry projects involved geometry topics at the junior high school. One of the projects was the Wingko Babat rainbow which involved local wisdom. Through EDP, students have the chance to develop their mathematical creative thinking abilities. In addition, the integration of STEAM-geometry projects fosters the development of 21st-century learning competencies, such as communication, cooperation, critical thinking, and creative problem-solving. The designed activities on STEAM-Geometry projects allow students to think creatively in elaborating the Engineering Design Process. The EDP on Geometry project enables students to think creatively. The findings imply that teaching geometry can be a possibility to develop the student's mathematical creativity through the engineering design process in STEAM activities. Moreover, we report that the design activities are not only about comprehension of geometry through design activities but also foster creativity by applying STEAM principles in the engineering design process. Furthermore, the results imply that the acquisition of 21st-century skills should be accommodated in the mathematics learning process. However, because of the limitations of this study, more research is required to increase the size of the research sample and the range of mathematical topics covered in junior high school curricula. Further research could investigate how varying levels of cultural integration impact engagement and learning outcomes and could reveal optimal approaches for diverse student populations. Additionally, examining the role of collaboration in STEAM activities, particularly the balance between individual and group work, may provide insights into enhancing creativity and critical thinking. Researching effective scaffolding strategies for the engineering design process based on students' prior knowledge would also be valuable. Lastly, longitudinal studies tracking the development of skills like spatial reasoning and creativity over time could clarify the lasting impacts of STEAM education.

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Declarations

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