



Examining Lesson Quality: An In-Depth Analysis of STEM-based Lesson Design Crafted by Preservice Elementary Teachers

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Abstract: Due to its significance in fostering 21st-century skills, Science, Technology, Engineering, and Mathematics (STEM) education has rapidly evolved across the country. However, designing effective and meaningful STEM-based lessons is still challenging, especially at the elementary school level. Thus, future elementary teachers should be trained to develop integrated STEM-based lesson plans. This research aims to explore the quality of STEM-based lessons designed by pre-service elementary teachers. This study analyzed six STEM-based lesson plans created by 32 preservice elementary teachers as a final group project in the STEM Learning in Elementary School course. Employing a descriptive analysis method, the study evaluated the lesson plans using STEM Integration Curriculum Assessment (STEM-ICA) indicators to shed light on the lesson design quality. Findings reveal varying scores across STEM-ICA indicators, emphasizing ideal science integration but indicating room for improvement in mathematics integration within the lesson. Assessment alignment and the need for stronger connections in engineering design activities are highlighted. This contributes to discussions on enhancing preparation programs for high-quality STEM educators in elementary schools.

Keywords: STEM education, preservice teachers, lesson design, elementary school

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INTRODUCTION

STEM education, an acronym for Science, Technology, Engineering, and Mathematics, has witnessed a rapid evolution on a global scale, reflecting a paradigm shift in educational priorities. In Indonesia, as in many other countries, STEM education's urgency has intensified in response to contemporary challenges and opportunities. The economic implications of STEM education are profound, serving as the bedrock for a nation's competitiveness in technological innovation and overall economic prosperity. Countries strategically prioritizing and investing in STEM education will likely experience enhanced economic conditions and technological advancements (Netwong, 2018). This strategic emphasis on STEM education aligns with a broader global trend recognizing the transformative power of these disciplines in shaping the future. Moreover, STEM education is critical in cultivating a skilled workforce equipped with problem-solving and critical-thinking abilities. The ability to navigate complex challenges is imperative in today's interconnected world. A study by Dewi et al. (2023) underscores the role of STEM education in nurturing individuals with the skills necessary to grapple with intricate global issues, including global warming, cybersecurity threats, food crises, and broader sustainability concerns.

The implementation of STEM education in Indonesia, while advantageous, encounters various challenges, reflecting a complex landscape that extends beyond the nation's borders. A comprehensive understanding of these challenges requires an exploration of diverse facets, ranging from policy and facilities to teacher competence and curriculum alignment. Arlinwibowo et al. (2022) shed light on the inadequate policy and facilities that challenge the effective implementation of STEM-based lessons in Indonesia. The insufficiency of supportive policies and infrastructure can impede the seamless integration of STEM education into the educational system. This fact underscores the need for comprehensive policies and adequate resources to create an enabling environment for STEM education. Kaniawati et al. (2016) identify difficulties in designing STEM lessons as another obstacle in the Indonesian context. Teachers face challenges in designing and implementing STEM lessons at school due to an inadequate understanding of integrated STEM learning, exacerbated by the absence of an integrative STEM curriculum in teachers' education programs (Nuraeni et al., 2024). Practical STEM lessons require careful consideration of pedagogical strategies, cross-disciplinary connections, and real-world applications. The challenges highlighted in lesson design underscore the complexities of creating engaging and impactful STEM educational experiences. Sukiyani (2023) addresses the critical issue of teachers'

competence in integrating STEM subjects, pointing to a potential gap in the professional development of educators. The successful implementation of STEM education relies heavily on educators' ability to integrate science, technology, engineering, and mathematics seamlessly. This requirement necessitates ongoing professional development programs that enhance teachers' competencies in STEM integration. The challenges extend to curriculum and pedagogical aspects, as [Fakhrudin et al. \(2023\)](#) noted. The national curriculum in Indonesia lacks clear guidelines for teachers to align and translate STEM concepts into classroom practice. Despite this, the STEM approach holds significant potential to optimize cross-subject projects, aligning with the goals of the current Kurikulum Merdeka.

Implementing STEM education in Indonesia requires a comprehensive and sustained approach to teacher training ([Sukiyani, 2023](#); [Sulaeman et al., 2022](#)). It is crucial for this training to extend beyond experienced educators and initiate during the college or university years when individuals are enrolled as teacher education students. [Evagorou \(2024\)](#) finds that teacher preparation programs should equip future teachers to excel in understanding STEM and be skilful in designing and implementing STEM lessons. Therefore, making STEM preparation courses compulsory in teacher education programs is a strategic step toward building a foundation for effective STEM education. Research indicates that adequate training in STEM education significantly enhances future teachers' pedagogical content knowledge, skills, and strategies essential for successfully implementing STEM education in practice ([Utley et al., 2019](#)). Such training contributes to increased confidence among teachers, fostering a positive outlook on their ability to navigate the complexities of STEM education. The work of [Fenton and Essler-Petty \(2019\)](#) underscores the positive impact on teachers' self-efficacy in designing and implementing STEM lessons following adequate training. Moreover, participation in STEM practices during training equips teachers with collaborative skills, promoting the sharing of resources, ideas, and best practices with their peers. This collaborative environment creates opportunities for ongoing professional development, aligning with the dynamic nature of STEM fields that continuously evolve with new knowledge and technologies.

This study aims to analyze the effectiveness of STEM education preparation programs by evaluating the STEM-based lesson plans created by pre-service teachers who have undergone a STEM education course, addressing the gap in existing research regarding the practical application of STEM education training. Current studies regarding teacher professional development programs in K-12 STEM education mostly use data collected through interviews or survey instruments. It should also include product performance, such as lesson plans, to ensure program effectiveness ([Huang et al., 2022](#)). Therefore, this study's novelty lies in its focus on transitioning from STEM education training to practical lesson plan development. It contributes to the field by providing empirical evidence on the quality and practicality of these lesson plans, identifying strengths and weaknesses in current STEM teacher preparation programs, and underscoring the need for comprehensive and sustained STEM training to equip pre-service teachers for effective integration of STEM principles in their classrooms.

METHODS

This study used a descriptive analysis method, combining quantitative and qualitative approaches to understand STEM-based lesson plans developed by pre-service teachers comprehensively. Quantitative data collection and analysis can be followed up by qualitative data collection and analysis to interpret a phenomenon ([Creswell, 2014](#)). Descriptive analysis may serve as a standalone research approach, especially when the emphasis is on uncovering unexplored phenomena, revealing concealed patterns within extensive datasets, or diagnosing tangible real-world needs that justify policy or intervention and play an important role in educational research ([Loeb et al., 2017](#)). In this study, the numerical data obtained from scoring the lesson plan using STEM lesson design indicators was followed by a thorough analysis of the lesson plan and other documentation, such as national curriculum documents and lesson journals, to finally describe and understand the STEM-based lesson design crafted by the pre-service teachers that can further be considered for future improvement in STEM educator preparation programs. It is essential to realign and execute science teachers' training and development through lesson analysis using different best practices on STEM learning methodically and continuously ([Permanasari et al., 2021](#)).

The study was situated within a STEM Learning for The Elementary School course offered. The participants were 32 pre-service teachers in their sixth semester enrolled in the Elementary School Teacher Education Study Program. The course, worth three credits, is an elective that delves into the history, significance, and underlying theories of STEM education. Students are expected to analyze existing STEM education practices in elementary schools and apply their knowledge to design STEM learning experiences aligned with the current curriculum. Throughout the course, pre-service teachers engage in lectures covering the history and urgency of STEM education, STEM competency components, approaches to STEM education, and STEM integration into the curriculum. Participants participate in individual and group activities, including analyzing existing STEM learning,

applying the engineering design process to solve everyday problems, designing STEM-based lesson plans, and simulating lessons using the lesson study method. Pre-service teachers submit revised lesson plans based on simulation results at the course's conclusion.

The pre-service teacher submitted six STEM-based lesson designs at the end of the course. To evaluate the quality of the lesson design, it undergoes scoring using the STEM Integration Curriculum Assessment rubrics (STEM-ICA) developed by [Guzey et al. \(2016\)](#). STEM-ICA comprises nine aspects of lesson quality evaluation: 1) motivating and engaging context; 2) engineering design; 3) science content integration; 4) mathematics content integration; 5) instructional strategies; 6) teamwork; 7) communication; 8) assessment; and 9) organization. Each item is rated on a five-point scale, ranging from 0 (not present) to 4 (excellent). The STEM-ICA has been appropriate as a guide to developing STEM units. It has also proven that it can be used as a research tool because it undergoes consistency assessment involving expert reviewers ([Guzey et al., 2016](#)).

Before formulating their lesson designs, the pre-service teachers were not given the STEM-ICA rubrics. In the research process, pre-service teachers were introduced to the backward design framework, as proposed by Wiggins and McTighe (1998), to guide the development of their lesson plans. This strategy involved a sequential approach where teachers began formulating learning objectives aligned with curriculum standards. Subsequently, they identified assessment tasks before deriving them into specific learning activities. This process culminated in a lesson plan draft, which was expected to encompass key components such as learning scenarios, learning media, assessment strategies, and students' worksheets.

The expected components in the final draft of the lesson plan included comprehensive learning scenarios that contextualize the educational experience, suitable learning media to enhance engagement and understanding, well-defined assessment strategies to evaluate student progress, and students' worksheets to reinforce and extend the learning content. Following this structured process, the submitted lesson plans were assessed using the STEM Integration Curriculum Assessment (STEM-ICA) rubrics. This multifaceted evaluation tool was employed to gauge the effectiveness and alignment of the lesson plans with STEM education criteria. After submitting their final STEM-based lesson designs, the lecturer reviewed and assessed them to evaluate the overall quality of the developed lessons. Subsequently, the scores for each lesson unit were compiled to assess how well each lesson met the STEM-ICA criteria. Additionally, the average score for each of the nine STEM-ICA aspects was calculated to identify areas of strength and aspects that require improvement.

RESULT AND DISCUSSION

In the research, six pre-service teachers developed six lesson plans, forming an integral part of their final assignment within the STEM Learning for Elementary School course. Each group crafted a lesson plan intended for two learning periods, with each lesson lasting for 70 minutes. A breakdown of the lesson plans reveals that all units are designed for the upper elementary level; four were tailored for fourth-grade students, one for fifth-grade, and another for sixth-grade students. This finding aligns with [Yanthi et al. \(2019\)](#) that teachers tend to perceive that the national curriculum strongly promotes STEM learning at the upper elementary school level. Notably, half of the lesson plans aligned with the latest national curriculum, the Emancipated Curriculum, while the remaining half adhered to the 2013 curriculum standards. The details of topic or theme distribution can be found in [Table 1](#).

Table 1. Overview of STEM lesson plans

Topic/Theme	Title of Engineering Challenge	Curriculum	Grade level
Transforming Energy	Wind-Powered Rocket Car	Emancipated Curriculum	4
Forces around Us	Build a Boat	Emancipated Curriculum	4
Why Don't We Float in The Air?	Lunch in Outer Space	Emancipated Curriculum	4
Residential Environment	Catapult Project	2013	4
Health is Essential	Your Blood Flow	2013	5
Entrepreneurship	Magnetic Powered Car	2013	6

The distribution of grade levels in the designed lesson plans showcases a focus on fourth-grade content, which may indicate a deliberate alignment with foundational STEM concepts at an earlier educational stage. The dichotomy in curriculum usage, with half adopting the Emancipated Curriculum and the other half adhering to the 2013 curriculum standards, could reflect the transitional nature of educational policies during the study period. The shift to the Emancipated Curriculum serves as a way to tackle the educational crisis in Indonesia,

indicated by low achievement in PISA 2018 (Ellen & Sudimantara, 2023) and the shift also triggered by the Covid-19 Pandemic (Rohmah et al., 2024). According to Kemendikbud (2023), more than 140 thousand schools have implemented the Emancipated Curriculum since it was first launched in 2022. In 2024, the Indonesian Ministry of Education declared the emancipated curriculum a national curriculum starting from the 2024/2025 academic year. However, the implementation is according to each school's readiness, with a transition period of up to three years.

Interestingly, the thematic concentration of the lesson plans demonstrates a noticeable inclination toward physics concepts. This trend holds even for two lesson plans incorporated within the entrepreneurship and environment themes of the 2013 Curriculum. This finding contradicts previous studies by Pleasants et al. (2021), who found no distinctions in the extent of conceptual connections among units in life science, physical science, and earth/space science with the engineering-based lesson plan. This emphasis on physics concepts may suggest a deliberate effort to integrate practical and hands-on applications, aligning with the experiential nature of STEM education. Additionally, the research findings highlight a unique focus on the biological sciences in one of the lesson plans, specifically concerning diseases in the human circulatory system. This thematic choice may indicate a broader effort to infuse health and biological literacy within STEM education, addressing real-world health challenges. The research findings, thus, offer insights into the pedagogical decisions made by pre-service teachers, reflecting the interplay of curriculum standards, thematic choices, and the targeted grade levels in the context of STEM education. To understand how well each lesson design meets the criteria of quality STEM lessons, the STEM-ICA score is outlined in Table 2 below.

Table 2. Results of STEM-based lesson plan assessment

Title	STEM-ICA aspects									Total
	1	2	3	4	5	6	7	8	9	
Wind-Powered Rocket Car (WPRC)	2	3	4	2	3	3	3	3	3	26
Build a Boat (BB)	3	3	4	2	4	3	3	3	3	28
Lunch in Outer Space (LOS)	3	2	4	2	3	4	3	2	3	26
Catapult Project (CP)	3	3	4	4	4	3	4	3	4	32
Your Blood Flow (YBF)	2	2	4	4	3	3	4	3	4	29
Magnetic Powered Car (MPC)	4	3	4	1	2	3	3	2	3	25

Description:

1) motivating and engaging context; 2) engineering design; 3) science content integration; 4) mathematics content integration; 5) instructional strategies; 6) teamwork; 7) communication; 8) assessment; and 9) organization

The presented results in Table 2 offer insights into the performance of each lesson plan based on the STEM Integration Curriculum Assessment (STEM-ICA) indicators. Notably, the Catapult Project (CP) unit emerged as the highest-scoring lesson plan, while the Magnetic Powered Car (MPC) and Lunch in Outer Space (LoS) units received the lowest scores. As reflected in Table 2, the research findings underscore the diversity in scores across STEM-ICA indicators for each lesson plan. This variability suggests that the quality and effectiveness of the lesson plans are not uniform and exhibit distinct strengths and weaknesses. This nuanced evaluation allows for a detailed understanding of the areas where each unit excels or requires improvement.

The Magnetic Powered Car (MPC) unit is singled out for having the lowest scores. The deficiency primarily concerns integrating mathematical concepts within the lesson and assessment components. This finding indicates a potential gap in addressing mathematical standards within the MPC unit, contrasting with its predominant emphasis on science concepts. Similar mathematical disintegration was found in Build a Boat (BB) and Lunch in Outer Space (LOS) units.

The Wind-Powered Rocket Car (WPRC) and Your Blood Flow (YBF) units are highlighted for their absence of global or societal contexts. The unit relies solely on broken toys as individual problem contexts, which may limit its capacity to connect with broader real-world issues. This finding underscores the significance of incorporating meaningful contexts in STEM lessons to enhance relevance and engagement (National Research Council, 2012; NGSS, 2013). In contrast, the Catapult Project consistently scores between 3 and 4 across all STEM-ICA criteria. These scores indicate a well-designed unit that effectively facilitates student learning in STEM subjects. The unit aligns with appropriate grade-level standards, suggesting a comprehensive and balanced approach to fostering an understanding of STEM concepts. The success of the Catapult Project highlights the importance of a holistic and integrated STEM curriculum, according to Bybee (2013) and National Research Council (2012). Further analysis reveals how the overall units are seen from the lenses of each STEM-ICA indicator. The total score of each indicator is illustrated in Figure 1 below.

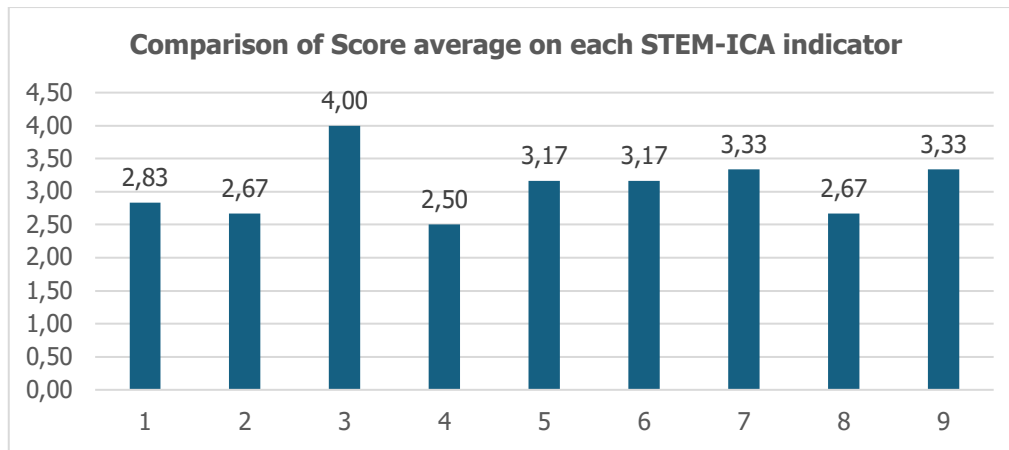


Figure 1. Comparison of Score average on each STEM-ICA indicator

Description:

1) motivating and engaging context; 2) engineering design; 3) science content integration; 4) mathematics content integration; 5) instructional strategies; 6) teamwork; 7) communication; 8) assessment; and 9) organization

The average score for motivating and engaging context is 2.83, indicating that the problem context should be improved in some units to make it more relatable to global problems or current issues. Among the six units, the MPC unit is the only one featuring a highly captivating context, earning a score of 4. This distinction is attributed to the unit's introduction of the context surrounding air pollution in the city, stemming from pollutants emitted by vehicles. The issue contributes to the local weather feeling increasingly hotter, reflecting the actual conditions in the city. Furthermore, this problem is interconnected with global concerns related to climate change. Consequently, the unit offers students valuable opportunities to engage in the engineering process within a partially realistic scenario, prompting them to devise vehicles utilizing alternative energy sources to replace polluting fuels. By doing so, the unit prompts for achieving the targets concerning the objectives of SDG-13 (He et al., 2023). Conversely, regarding problem orientation, WPRC units exclusively delve into problems about damaged toys without establishing a link to a broader and contemporary problem context, such as global, economic, or current issues. Similarly, the YBF unit with organ system health theme falls short in connecting the problem context of cardiovascular system diseases to global concerns associated with this ailment despite it being one of the most lethal diseases worldwide (Gaidai et al., 2023).

Another notable finding is that some units, such as LOS and BB, present the problem in the form of comics consisting of pictures depicting the problem situation. According to Piaget, this problem context presentation may increase students' engagement toward the lesson, remembering that students at the elementary school level are in the concrete operational stage of cognitive development. As seen from the sample of problem context in Figure 2 below, students were actually given information about constraints on materials that can be used as provided in the comics. For instance, in Figure 2a there are pictures of scissors, aluminium foil, used plastic cups, etc, which are the materials that the students can use to design the boat model as the solution to the problem.



a



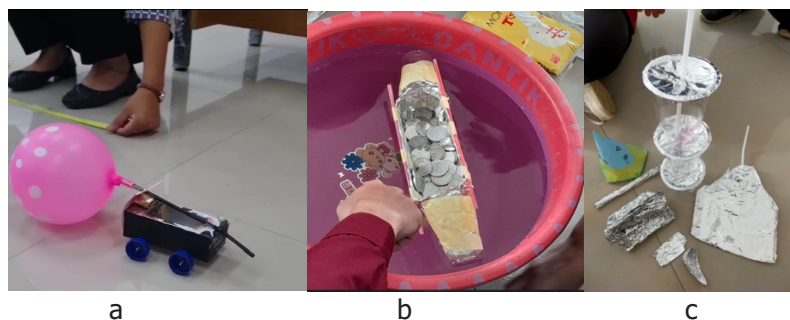
b

Figure 2. Problem presentation in the unit:

a) Build a Boat and b) Lunch in Outer Space

All units have been organized following the engineering design process (EDP), which involves identifying problems and engineering challenges, creating solution designs, constructing solutions, and engaging in testing and improvement stages. For instance, in the WRPC unit, students were tasked with devising a simple, functional air-powered car. In another unit, students were required to build a boat as a solution model for addressing flooding issues. The Lunch in Outer Space unit demanded the design and testing of food packaging suitable for astronauts working in the international space station. The remaining engineering challenges encompassed the creation of a catapult for recycling used ice cream sticks and constructing magnet-powered cars. In the Your Blood Flow unit, a reverse engineering approach was applied, where students were tasked with constructing cardiovascular system models and simulating related diseases.

However, the average score for this aspect is still only 2.67 because none of the units manage to fulfil all the criteria for an ideal engineering design challenge, particularly in fostering an understanding of engineering and the practice of engineers in the workplace. Given the increasing demand for STEM professionals in the current and future world, it is crucial to expose students to engineering (Nuraeni, 2023). In addition, San-Miguel et al. (2019) argue that the elementary school level is a critical moment to increase exposure to STEM-related careers. Among the units, "Lunch in Outer Space" (LOS) and "Your Blood Flow" (YBF) fall short in providing students with the opportunity to pinpoint potential improvements based on their testing results, unlike the other units that allow students to redesign solutions through drawing. The teacher could guide students on enhancing designs by adding more detail to redesign activities, and this could improve students' application of STEM knowledge (King & English, 2016). As previously discussed, pre-service teachers were allowed to simulate their lesson designs through peer teaching sessions. These peer teaching sessions encompassed engineering activities aimed at verifying the appropriateness of the design challenge for the specified grade level. Additionally, the activities were assessed for alignment with educational standards and adherence to the allocated time. Various constructed product samples were generated during these peer teaching sessions, providing tangible evidence of the applied engineering activities. The ensuing figures depict the outcomes produced throughout these collaborative teaching exercises.



a

b

c

Figure 3. Examples of products in engineering activity:

a) Wind-powered cars; b) Boat from aluminium foil; c) Food and drink packages for astronauts.

The research findings underscore the effectiveness of integrating science content into STEM lessons, as evidenced by the highest average rating of 4.00 compared to other indicators. This score implies successfully integrating science topics across all units, contributing to a comprehensive, interdisciplinary learning experience. In the WPRC unit, incorporating concepts related to energy resources and energy transformation within everyday life aligns with the broader understanding of science in practical contexts. This finding is consistent with the opinion of [Bybee \(2013\)](#) and [Suryani et al. \(2023\)](#), emphasizing the importance of connecting STEM subjects to real-world applications to enhance student engagement and understanding. Despite facing challenges, teachers integrating multidisciplinary real-world problems, according to [Widjaja et al. \(2019\)](#), observe increased student engagement, enjoyment, and students' apparent autonomy and ownership of the projects.

The Build a Boat unit introduces students to Archimedes' principle, explicitly focusing on the buoyant force, which aligns with the recommendations made by [Guzey et al. \(2016\)](#), emphasizing the significance of hands-on experiences in STEM education to foster a deeper understanding of scientific principles. In line with that, [Su and Chen \(2023\)](#) explain that engaging in hands-on STEM-based learning enhances students' cognitive abilities to overcome challenges and obstacles, leading to improved learning outcomes. The Lunch in Outer Space unit explores the effects of gravity force in space on astronauts' lives. This finding resonates with the research by [Stohlmann et al. \(2012\)](#) that STEM lessons should emphasize the value of incorporating space-related topics to stimulate students' interest and curiosity in science. The catapult project unit's design centered on analyzing the relationship between force and object movement that promotes scientific inquiry advocated by highlighting the importance of fostering investigative skills in science education. The YBF unit's connection to the function and diseases of the cardiovascular system emphasizes the integration of life science topics in STEM education. Finally, the MPC unit related to magnet properties is consistent with the research by [National Research Council \(2012\)](#), advocating for the inclusion of physical science concepts, such as magnetism, to enhance students' understanding of the natural world.

The research findings underscore a noticeable deficit in integrating mathematical content within the STEM lesson plans, reflected in the lowest average score of 2.50. The explicit integration of mathematical content is discernible in only two units—CP and YBF. This finding aligns with [Maass et al. \(2019\)](#) that although mathematics is widely recognized as the foundation of all other STEM fields, compelling evidence indicates its often overlooked role in integrated STEM education. Studies have also shown that prospective teachers struggle with creating learning tasks that align well with the mathematics curriculum ([Poonpaiboonpipat, 2021](#); [Sevimli & Ünal, 2022](#)). One lecturer with a science education background facilitated the course, causing a lack of discussion about relevant mathematics concepts or topics. [Poonpaiboonpipat \(2021\)](#) highlights that ambiguity and differing interpretations of the integration process can emerge from those with different backgrounds.

In the CP unit, students apply mathematical concepts practically by identifying the optimal catapult for achieving maximum throwing distance. This learning experience provides hands-on activities that connect STEM subjects to real-world problem-solving scenarios ([Bybee, 2013](#)). Similarly, the YBF unit integrates mathematics into its framework by requiring students to determine and compare blood flow rates in clear and clogged blood vessels. This approach aligns with the recommendations made by [Guzey et al. \(2016\)](#), emphasizing the integration of mathematics to enhance students' engineering self-efficacy and outcome expectancy. In contrast, while incorporating activities involving measurements and mathematical concepts like geometry, the remaining units fall short in explicitly addressing corresponding mathematics standards in their lesson plans. This finding emphasizes the need for a more explicit and intentional approach to integrating mathematical content. [Ben-Jacob \(2019\)](#) argues that mathematics serves as the cornerstone of other STEM fields. This fact indicates a critical area for improvement in ensuring a well-rounded, interdisciplinary approach. [National Research Council \(2014\)](#) emphasizes that integrating mathematics within STEM education is essential to enhance students' problem-solving skills and analytical thinking. The sooner we can engage students in mathematics and help them succeed, the higher their future academic accomplishments will be.

The instructional strategies employed in the five units demonstrate a consistent score range of 3 to 4 points, resulting in a 3.17 score average, indicative of a curriculum that prioritizes student-centred activities and hands-on tasks. This finding shows that all units apply the principles of effective STEM education, emphasizing the importance of active engagement and experiential learning ([National Research Council, 2012](#)). Incorporating student-centered activities reflects the recommendations ([National Research Council, 2014](#); [Suryani et al., 2023](#)), emphasizing the significance of fostering problem-solving and inquiry-based learning approaches in STEM education. In addition, Inquiry-based learning can promote and expedite the integration of STEM subjects in education ([Deák et al., 2021](#)). This approach encourages students to construct solutions to real-world problems, enhancing their problem-solving and critical-thinking skills. Including hands-on tasks is consistent with the research conducted by [Guzey et al. \(2016\)](#), highlighting the positive impact of hands-on experiences on students' engagement and understanding of STEM subjects. Practical, interactive tasks contribute to a more immersive learning experience. Some units also emphasize data collection and analysis, employing tabular formats to

record results promoting evidence-based learning that might increase student engagement. Students are found to be more likely to be fully engaged in their learning when teachers use evidence-based classroom management techniques (Gage et al., 2018).

The finding that only one unit lacks explicit written instructions for data analysis echoes the importance of clear communication and guidance in instruction. Providing explicit instructions ensures students can effectively carry out data analysis tasks, contributing to a more cohesive learning experience. To involve students in the process of inquiry, they must practice defining what qualifies as data and recognizing variables or parameters (Tytler & Self, 2020). All units are designed for a single meeting; thus, assessing every lesson's connection to the overall design challenge is difficult. However, including a recall activity at the beginning, as outlined in the lesson plan, aligns with the principles of scaffolding in education. This approach ensures students build on prior knowledge, fostering continuity and coherence in the learning experience.

As reflected in the units, the teamwork aspect garners an average score of 3.17, indicative of a balanced emphasis on collaborative learning strategies. The lesson plan explicitly outlines the necessity for student collaboration within groups comprising 4 to 6 members. This collaborative approach resonates with the cooperative learning strategies, emphasizing the positive impact of peer interaction on academic achievement and social skills development. The instructional strategies planned for the lesson could actively foster positive team interactions during group work, which aligns with the principles of positive interdependence (Butera & Buchs, 2019). These elements emphasize the importance of structuring tasks to require interdependence among group members and encouraging supportive interactions. Group collaborative efforts provide students with valuable opportunities for verbal communication with their peers. This aligns with the findings of Lou et al. (2001), highlighting the positive correlation between verbal interaction in small groups and enhanced learning outcomes. All units promote group discussion activities that enhance elementary school students' grasp of science concepts (Budiastini et al., 2023). Moreover, incorporating opportunities for students to offer comments and feedback to other groups during presentations aligns with the concept of individual accountability within cooperative learning (Butera & Buchs, 2019). This strategy ensures that each student is actively engaged and responsible for contributing to the group's work. The reflection session is at the conclusion of each unit, where students contemplate their learning experience. This reflective practice contributes to students' social and emotional development. The communication aspect, gauged with an average score of 3.33 across all units, underscores the significance placed on fostering practical communication skills within the context of STEM education. This aligns with contemporary educational paradigms that recognize communication as a fundamental 21st-century skill, as all units embody a holistic approach that integrates oral and written communication skills. An in-depth analysis of the lesson designs elucidates that the activities embedded in the lessons deliberately require students to articulate science concepts both orally and in written form. This multifaceted approach to communication mirrors the comprehensive communication skills advocated by the National Research Council (2012). It aligns with the integrative STEM education approach, emphasizing the interconnectedness of science, technology, engineering, and mathematics.

Furthermore, the integration of engineering thinking is evident in the instructional design, as students are encouraged to understand engineering principles and communicate these ideas effectively. The explicit requirement for students to visually represent their design solutions through drawings reflects research by Evagorou et al. (2015), that visual representations are essential to scientific practices and facilitate more precise communication of complex ideas. Cheng (2021) even emphasizes that visual representations are essential in science development, and scientists use them to communicate their discoveries, which could help students connect with scientific practices and promote scientific literacy. The post-construction phase involves students presenting their solution models to their peers, who assume the role of 'clients.' This practice aligns with contemporary educational trends emphasizing project-based learning and peer collaboration. It resonates with the idea that students, in adopting the role of 'clients,' not only assess the technical aspects of the solution but also engage in meaningful dialogue, fostering a communicative exchange reflective of real-world engineering practices.

With an average score of 2.67, the assessment aspect illuminates the multifaceted evaluation framework integrated into the lesson designs. This comprehensive approach aligns with contemporary educational paradigms that recognize the need for varied assessment strategies catering to diverse learning domains, including cognitive, affective, and psychomotor domains. Four out of the six units in cognitive assessment showcase a meticulous plan, incorporating Bloom's taxonomy to delineate cognitive levels. However, a noteworthy finding indicates that some question items within these units exhibit inappropriate operational words, potentially challenging the alignment between assessment tools and the overarching lesson objectives. Furthermore, these four units exhibit a commendable commitment to attitudinal assessment, evidenced by well-defined rubrics aligning with either the Pancasila Learner Profiles indicators in the Emancipated Curriculum or the Character Education indicators in the 2013 National Curriculum. This adherence to attitudinal assessment aligns with the current emphasis on holistic student development encompassing cognitive and affective

dimensions.

In the psychomotor domain, the employed rubrics span various aspects of performance evaluation, encompassing planning, implementation of solution construction, and results reporting. The criteria for product assessment delve into functionality, aesthetics, and creativity, providing a comprehensive lens for evaluating students' engineering solutions. Notably, including collaboration, critical thinking, responsibility, curiosity, and independence within the performance assessment rubrics for BB and LOS units introduces an interesting dimension, as it is proven to enable educators to assess 21st-century skills in STEM-based learning (Hamdu et al., 2020). While traditionally associated with cognitive or affective domains, these qualities are integrated into assessing hands-on, practical skills, reflecting a nuanced understanding of holistic student competencies (Wren & Gareis, 2019). The organization aspect of the lesson design emerges as a crucial facet, contributing significantly to the overall effectiveness of STEM-based educational interventions. Despite the general presence of an organizational structure encompassing lesson objectives, curriculum standards, learning experiences, formative assessment techniques, and students' worksheets across all units, nuances within this dimension highlight both strengths and areas for improvement.

The average score of 3.33 reflects a commendable effort but also indicates room for enhancement. Notably, the Catapult Project (CP) and Your Blood Flow (YBF) units stand out by meeting all the required criteria outlined in the STEM Integration Curriculum Assessment (STEM-ICA). In particular, these two units formulate learning objectives and articulate expected student behaviors precisely through operational verbs. This alignment between objectives and desired behaviors is crucial for providing a clear roadmap for educators and learners, fostering a focused and purposeful learning experience. Moreover, CP and YBF units display a noteworthy integration of standards for mathematics competencies, promoting a multi-disciplinary approach within STEM education. This strategic alignment with various STEM disciplines enhances the holistic development of students' 21st-century skills (Dharin et al., 2023; Nuraeni, 2023; Nuraeni et al., 2023; Zainil et al., 2023) and characters (Hidayati et al., 2019), aligning with contemporary educational perspectives. Another standout feature in these units is the logical and sequential organization of learning activities, delineating an adequate flow from introductory sessions to main activities and closing sessions. This meticulous structuring, including allocated timeframes, enhances the overall coherence and effectiveness of the instructional design. Furthermore, these exemplary units underscore the significance of comprehensive assessment planning, providing a blueprint for formative assessment instruments such as rubrics for performance evaluation and item tests aligned with Bloom's taxonomy. This aligns with the broader discourse on the importance of well-structured assessments for gauging student learning outcomes. While the average score suggests a reasonably organized lesson design across units, the specific strengths showcased by CP and YBF units offer valuable insights for refining organizational elements within STEM-based lesson plans. Diverse scores across STEM-ICA metrics indicate the requirement for focused interventions in some respects and offer valuable insights into strategies to develop more effective preparatory courses for future STEM educators at the elementary school level. The identified need for improvement in problem context engagement suggests that a compelling purpose related to global issues or current events could enhance student engagement. This aspect necessitates the development of strategies to infuse real-world relevance into problem-oriented scenarios, fostering a deeper connection with elementary school students. In addition, the identified gap in mathematics integration highlights the need for a more intentional approach to infuse mathematical concepts seamlessly into STEM lessons that could be made possible through course team teaching involving lecturers from at least science and mathematics backgrounds. Involving lecturers with engineering backgrounds might also be beneficial in addressing the disconnect between engineering design activities and the core concepts of engineering within the lesson unit developed by the pre-service teacher. The research also underlines challenges in assessment alignment with learning objectives, emphasizing the significance of practices for pre-service teachers taking the course to develop clear and purposeful assessments for STEM-based lessons.

CONCLUSION

The analysis of STEM-based lesson plans designed by pre-service teachers enrolled in the STEM for Elementary School course provides valuable insights into the lesson design quality. Findings reveal varying scores across STEM-ICA indicators. While science integrations are evident across all units, particular challenges in other aspects demand targeted interventions, such as in problem context engagement, mathematics integration, assessment alignment with learning objectives and disconnection between engineering design activities and the core concepts of engineering. Implications for STEM educator preparation programs include 1) incorporation of strategies to enhance problem context engagement, with an emphasis on real-world relevance and connections to global issues; 2) a targeted focus on equipping pre-service teachers with strategies for effective mathematics integration within STEM lessons; 3) integration of training modules that emphasize the importance of clear assessment alignment with learning objectives, ensuring a purposeful and cohesive

evaluation process; and 4) inclusion of specific training components on aligning engineering design activities with the broader principles of engineering, fostering a comprehensive understanding of the discipline. The identified areas for improvement offer a roadmap for developing effective STEM educator preparation programs, ensuring that future educators are well-equipped to design integrative, meaningful, and engaging STEM lessons for elementary school students.

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