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# Literacy skills through the use of digital STEAM-inquiry learning modules: A comparative study of urban and rural elementary schools in Indonesia

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**Abstract**
Mathematical literacy is very important for students, especially in solving mathematical problems related to everyday life. It is important at the elementary school level because it is the basis for abilities at the next school level. In reality, the current learning in schools is not optimally focused on increasing mathematical literacy. This research aims to analyze differences in students' literacy abilities based on learning approach (digital STEAM-inquiry learning [digital STEAMIL] module vs. conventional), geography (urban vs. rural), gender (male vs. female), and internet access. The research conducted was a quasi-experiment with a nonequivalent posttest-only group design. The subjects in this study were elementary school students in urban (N = 77) and rural areas (N = 65). Data was collected through technical tests (mathematical literacy post-test). Research data analysis used inferential statistics, ANOVA and post-hoc test (LSD). The results of the research showed that at the 95% confidence level, there was a difference in students' mathematical literacy between the use of the digital STEAMIL module and conventional. There are differences based on demographics, where urban students' mathematical literacy skills are better than rural students' after learning with the digital STEAMIL module. However, there was no difference in gender (male vs. female) in mathematical literacy abilities. The intensity of internet access influences literacy skills after using the digital STEAMIL module, students who frequently access the internet tend to have higher mathematical literacy.

**Keywords:** elementary school, inquiry learning, mathematical literacy, STEAMIL, urban and rural

## INTRODUCTION

Indonesia's current education curriculum is designed to emphasize key 21st century skills, such as communication, collaboration, creativity, and adaptability (Kemendikbud, 2023). These competencies are essential in meeting the demands of contemporary education (Salim, 2019). On an international scale, mathematical literacy is widely recognized as a crucial indicator of educational success (Drew, 2012; Holenstein et al., 2022). In Indonesia, educational competency standards also emphasize mathematical literacy. For example, the program for international student assessment (PISA) includes mathematical literacy as one of its core domains (OECD, 2013; Stacey, 2012).

Mathematical literacy refers to the ability to formulate, apply, and interpret mathematics in real-world contexts (Basam et al., 2017; Ojose, 2011), enabling individuals to solve both routine and complex mathematical problems in everyday life (Jailani et al., 2020; OECD, 2019). It also encompasses the capacity to analyze information presented through various visual representations, such as graphs, images, and tables (Saefurohman et al., 2023), thereby fostering students' mathematical reasoning (Rizki & Priatna, 2019). Strengthening foundational literacy skills is crucial, as they serve as the bedrock for students' advancement to higher education (Anwas et al., 2022).

Despite these goals, improving student performance in Indonesia remains a challenge. According to recent PISA assessments, Indonesia continues to perform


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**Contribution to the literature**

- This study proposes using digital STEAM modules and inquiry learning to support mathematical literacy in elementary school students.
- This study also provides information on how the use of STEAM-based digital modules and inquiry learning is implemented in schools in rural and urban areas.
- The empirical analysis in this study confirms that the use of STEAM digital modules can be used to optimize learning outcomes at the elementary school level, especially mathematical literacy skills.
- The findings in this study highlight the close relationship between the various theories and demonstrate the importance of teaching materials designed with STEAM and inquiry learning in mind.

poorly in mathematics. In the 2018 PISA survey, the country's average score was 379, placing it at level 1 (Schleicher, 2019). By 2022, the average score had declined further to 366, ranking Indonesia 9th from the bottom (OECD, 2023). National assessment data for elementary schools in 2021 and 2022 reveal that less than 50% of students reached the minimum competency level in mathematical literacy (Pusmendik-Kemendikbud, 2022). Numerous studies on mathematical literacy at both the elementary and secondary levels underscore this issue. For instance, Mahmudin et al. (2023), report that research on "mathematical literacy" has been extensive up to 2023, with findings consistently showing that elementary students in Indonesia have low levels of mathematical literacy (Putra & Agmadya, 2021). These findings highlight critical deficiencies in literacy achievements among elementary students, underscoring the need for targeted interventions. So concrete solutions and real steps are needed to resolve these problems.

Empirical studies suggest that integrating technology into education can significantly improve learning outcomes. The use of digital tools in education not only helps students to acquire new knowledge but also stimulates creativity, enhances cognitive skills, and promotes innovative learning strategies (Han, 2023), using information and communications technology (ICT) effectively in engaging students' skills (Nicole et al., 2023). Technology integration is increasingly important at all levels of education (Ghavifekr & Rosdy, 2015), especially in mathematics, where digital tools can play a transformative role (Temel & Gür, 2022). Educational innovations that incorporate technology into mathematics instruction can make learning more engaging and effective (Dewita et al., 2019). Result of research shows that the implementation of technology in teaching materials can support mathematical literacy abilities, and improve mathematical abilities (Flavell et al., 2019). Furthermore, evidence suggests that students with higher literacy skills are more likely to use the internet frequently, which further enhances their learning experiences (Hong et al., 2020)

The use of educational technology has been found to have a more significant impact on elementary students compared to secondary school students (Li & Ma, 2010). One of the learning frameworks that effectively incorporates technology is science, technology, engineering, art, and mathematics (STEAM) education. Integrating technology into STEAM-based learning has been explored as a method to enhance student engagement (Roberts et al., 2019). STEAM education is especially beneficial in formal education settings (Young et al., 2022). In Indonesia, learning by integrating technology has been designed to be one of the aims of the curriculum, especially the one currently used, namely the *merdeka curriculum*. Incorporating STEAM into the *merdeka curriculum* has the potential to improve critical thinking and problem-solving abilities (Naufal et al., 2024), and creativity (Wu et al., 2022). The design and development of STEAM-based projects have been shown to strengthen students' reasoning abilities (Elfrida et al., 2023). Additionally, several studies suggest that STEAM-integrated teaching materials can support elementary students' mathematical literacy (Susanto et al., 2024).

In applying STEAM to classroom learning, especially at the elementary school level, it is necessary to integrate projects that are easy to understand. The inquiry approach allows it to be applied in already designed STEAM projects. Implementation of inquiry can support problem-solving abilities and student motivation (Ma et al., 2022; Martín-Páez et al., 2019). According to Basam et al. (2017), the use of teaching materials with an inquiry approach supports students' learning literacy. Some empirical data also finds that inquiry-based learning has a significant impact on students' scientific literacy and character (Alim et al., 2020). Active learning with an inquiry approach is worthy of attracting student interest (Koswojo & Pratidhina, 2023). Guided inquiry learning can improve students' metacognitive skills better than conventional methods (Hastuti et al., 2020). Therefore, the combination of the STEAM model and the inquiry approach can be one of the designs for teaching materials that can support students' thinking skills in elementary schools.

This research primarily aims to evaluate the effectiveness of the digital STEAM-inquiry learning (digital STEAMIL) module in improving elementary students' literacy skills in urban and rural areas. The main research questions (RQs) are:

**RQ1.** Is there a difference in the average student's mathematical literacy abilities between the use of the digital STEAMIL module and conventional learning?

**RQ2.** Is there a difference in the average mathematical literacy abilities of students between urban and rural schools?

**RQ3.** Are there differences in students' mathematical literacy abilities based on gender (male and female)?

**RQ4.** Are there differences in students' mathematical literacy abilities based on the intensity of internet usage (high medium, and low)?

## THEORETICAL FRAMEWORK

### Use of Technology in Elementary School Learning

The integration of technology into education, particularly in Indonesia, has surged since the COVID-19 pandemic. In schools, the incorporation of technology into teaching materials has been shown to improve the quality of education and enhance student engagement. Technology enables students to access a broad range of information and develop digital skills from an early age (Yuan & Liang, 2024). Technology helps teachers present material more interactively, such as through multimedia presentations, educational videos, and interesting learning applications (Margot & Kettler, 2019; Pappa et al., 2023).

Technology supports critical thinking, collaboration, and problem-solving skills (Li et al., 2024; Matos et al., 2019), enriches the learning experience (Halverson & Sheridan, 2014), and helps students explore their interests and potential (Mohebi, 2021). Additionally, technology fosters motivation by creating more interactive and engaging learning environments (Young, 2023). For educators, technology allows for more dynamic and interactive content delivery (Bell & Margot, 2019; Mammes, 2012).

In elementary schools, the use of technology has a significant positive impact on students by enhancing their learning experiences and providing access to diverse sources of information (Higgins et al., 2012). However, careful monitoring is necessary to mitigate potential negative consequences, such as distraction, dependency, and decreased social interaction (Ertmer & Ottenbreit-Leftwich, 2012).

Therefore, a balanced approach, along with appropriate guidance, is essential to help students maximize the benefits of technology (Chai & Kuech, 2015). In elementary settings, it is also important to ensure that technology use does not detract from face-to-face interactions with peers, which are crucial for students' holistic development (Harris & Hofer, 2011). Long-term improvements in mathematical learning at both the elementary and secondary levels can be achieved through the thoughtful integration of technology (Flavell et al., 2019).

### Implementation of STEAM in Elementary School Learning

The strategy for implementing the STEAM approach in elementary education begins with developing an integrated curriculum that merges science, technology, engineering, art, and mathematics into relevant, real-world projects (Chung, 2018; Utaminingsih et al., 2023). In practice, teachers can design thematic projects, such as creating simple tools to solve everyday problems (King et al., 2021), which promote active and collaborative learning (Beers, 2011), and communication (Miller, 2015), classrooms can be structured to foster exploration and creativity (Mouza, 2015). Techniques for implementing the STEAM approach in elementary schools can start by designing interdisciplinary projects that are relevant to students' daily lives (Kim & Park, 2012). For example, teachers can invite students to design and build a bridge model using simple materials, combining engineering and mathematical principles (Henita et al., 2023).

### Mathematical Literacy in Elementary Schools

Mathematical literacy is a key focus and an important indicator of educational success both internationally and in Indonesia. It is one of the primary competencies assessed in national evaluations and continuous assessments in Indonesia, as reflected in periodic assessments focusing on mathematical literacy (Pusmendik-Kemendikbud, 2022). Thus, introducing mathematical literacy from the elementary level is essential to ensure that students are equipped with this skill as they advance in their education. Mathematical literacy plays a vital role in fostering students' critical thinking and problem-solving abilities (Lester, 2013; Miller, 2013), communication (Alves et al., 2019); and enables them to effectively communicate and explain mathematical concepts (Becker & Park, 2011; Niss, 2015).

Elementary students often struggle with grasping abstract concepts, and mathematical literacy can serve as a bridge to help them comprehend these ideas. This ability can develop thinking skills to solve problems (Rizki & Priatna, 2019). By understanding basic mathematical concepts, students can apply this knowledge in everyday life (Apsari et al., 2023). For instance, they can use their understanding of addition and subtraction to count money or their knowledge of fractions to divide a pizza. Developing strong mathematical literacy enables students to connect mathematics with real-world situations, deepening their understanding of the practical relevance of mathematics in daily life (Miller & Reddy, 2022).

In measuring mathematical literacy at the elementary level, it is important to account for students' varying abilities. In Indonesia, literacy assessments focus on three cognitive levels: knowing, applying, and reasoning (Wijaya & Dewayani, 2021; Susanta et al., 2023b). To improve mathematical literacy, it is essential to present students with real-world problems (Gülçin & Masal, 2014). Research indicates that challenges with mathematical literacy in high school may stem from difficulties encountered at the elementary level (Firdaus & Herman, 2017). Studies also show that preschool children with higher literacy and math skills are more likely to attain educational qualifications in adolescence (Baumann et al., 2024). Therefore, it is crucial to emphasize literacy-based learning at the elementary level to establish a solid foundation for future academic success.

### Digital Learning in Urban vs. Rural Schools

A significant challenge in education is how to implement technology effectively in both urban and rural settings. Several factors must be considered, particularly when applying digital learning in these contrasting environments. Research indicates that access to a wide range of hardware and software fosters the development of students' digital skills (Lehmann & Mendez, 2021). Urban areas typically have better access to technology and infrastructure (Gomez & Martinez, 2019). with schools often equipped with modern facilities and high-speed internet connections (Alvarez & Calvo, 2020). This enables students to fully engage with interactive learning resources (Miller & Mendez, 2020). Studies further suggest that teachers in urban schools receive more frequent and advanced training in technology integration (Huang & Spector, 2019).

In contrast, rural schools face numerous challenges in implementing digital learning. Limited internet access and a lack of digital learning tools are the primary obstacles in remote schools (Nir & Nissim, 2020; Zhao & Li, 2019). While teachers in rural areas work to maximize the available technology, its impact tends to be less substantial. According to Sharma and Alavi (2020), efforts to improve technological access have been made, but the outcomes remain inadequate. Nevertheless, rural schools have a distinct advantage in the closer interactions between students and teachers. In these schools, social interaction and teacher-student support remain strong (Jansen & de Lange, 2019), helping to preserve collaborative and social values (Miller & Mendez, 2020). Research on elementary schools also indicates that literacy development varies by location-rural, urban, and transitional regions (Firdaus & Herman, 2017). Moreover, studies highlight a growing digital divide between urban and rural areas, particularly among teachers, which reflects disparities in digital environments and literacy levels. These differences affect teachers' ICT competencies, impacting their ability to integrate technology at varying levels (Zhao et al., 2021).

### Inquiry Learning in Elementary Schools

Inquiry learning plays a pivotal role in elementary education, enhancing students' conceptual understanding and motivating them to learn (Pedaste et al., 2015). This pedagogical approach encourages students not only to learn concepts but also to actively construct them (Yıldız & Demirci, 2021). Inquiry learning deep engagement, active participation in discussions, motivation, and collaboration (Gholam, 2019; Heindl, 2018; Wang, 2018). Key features of this method include problem-solving and critical thinking (Minner et al., 2010), offering students the opportunity to explore concepts (Lu & Lo, 2015), while also strengthening their social skills (Furtak et al., 2016).

This approach is particularly important for elementary students as it stimulates curiosity (Hmelo-Silver, 2004), promotes active engagement in meaningful learning experiences (Furtak et al., 2016); and helps develop both academic knowledge and social skills (Pedaste et al., 2015). So that this inquiry learning is in line with the curriculum objectives currently being implemented in elementary schools in Indonesia, namely the *merdeka curriculum*. One of the aims of this curriculum is to realize holistic and contextual student learning (Kemendikbud, 2023), it is relevant with inquiry learning. The application of inquiry-based learning in elementary schools, however, differs from that in higher education. Teachers must guide students through the learning process, facilitating discussions by asking relevant questions (Minner et al., 2010). The teacher must guide and direct the students so that these questions arise and are relevant to the material, which then collects data and interprets and presents the results.

## METHODS

### Research Design

This study employs a quasi-experimental design using a quantitative approach. A quasi-experimental approach was selected because the researcher utilized pre-existing groups rather than forming new ones. As Creswell (2014) explains, quantitative research seeks to provide a descriptive account of outcomes related to the research subjects. This aligns with the objective of the present study, which is to compare students' mathematical literacy outcomes using the digital STEAMIL module across rural and urban schools.

The study adopts a nonequivalent posttest-only group design with two treatment groups. One group received instruction using the digital STEAMIL module, while the other group followed conventional teaching methods. After the intervention, both groups were administered a mathematical literacy posttest (Sukmadinata, 2015). The research design is summarized in **Table 1** (Kadir, 2016).

**Table 1.** Research design

| Group | Treatment | Post-test |
|---|---|---|
| Urban | Digital STEAMIL module (E1)<br>Conventional (C) | *O* |
| Rural | Digital STEAMIL module (E2)<br>Conventional (C2) | |

## Research Sample

The sample for this study consists of 142 students from rural and urban schools in two provinces (Bengkulu and South Sumatera, Indonesian). Participants were drawn from state elementary schools (SES) in these regions using purposive sampling, to compare students across rural and urban contexts. Random class selection was conducted within the chosen schools. Eight schools were involved, with each assigned to either the experimental group (digital STEAMIL module) or the control group (conventional method). A detailed description of the sample is provided in **Table 2** (M = male and F = female).

## Data Collection

Data were collected through posttests administered to both treatment groups. The research instrument consisted of four open-ended questions designed to assess students' mathematical literacy, specifically tailored to the abilities of elementary school students. The test was constructed based on key indicators of mathematical literacy proposed by (Steen, 2001), which include mathematical thinking and reasoning, argumentation, modeling, problem-solving, representation, and communication. This test instrument was prepared based on a study of mathematics material at the fifth-grade elementary school level with a focus on numbers and geometry. When preparing each question, refer to these indicators presented in **Table 3** (Susanta et al., 2023a).

The instrument was scored according to the following criteria:

(1) a score of 3 was assigned for correct and complete answers (students answered 100% correctly),

(2) a score of 2 for partially correct or incomplete answers (this is chosen if there is an error in the calculation, the calculation process is incomplete, the analysis process is lacking), and

(3) a score of 0 for incorrect or missing responses.

The validity of the test was evaluated by two experts in elementary mathematics. The question validity process is carried out by providing an assessment sheet to the expert which focuses on assessing the material, language, and construction. The validation sheet for this question is arranged on a Linkert scale, (1) very bad, (2) bad, (3) fair, (4) good, and (5) very good. The results of two experts' assessments of the 4 questions were analyzed using Aiken's V (Aiken, 1980), with all items achieving a validity score above .5, indicating acceptable validity. The instrument underwent empirical testing on 18 fifth-grade students at a SES in Bengkulu City. This stage is carried out after selecting the trial school and then being given test questions for 1 meeting (60 minutes). The test results were assessed with a score range of 1-3 and analyzed using Cronbach's alpha with the help of SPSS. The reliability of the test was confirmed through Cronbach's alpha, yielding a value of .76, which indicates a high level of reliability (Cecil, 2010).

## Data Analysis

The data analysis involved both descriptive and inferential statistical methods. Descriptive statistics summarized students' mathematical literacy scores by calculating the mean, and standard deviation. These measures provided insights into the distribution of mathematical literacy levels across different groups. The

**Table 2.** Description sample of research

| No | Geography | Treatment | Sample |
|---|---|---|---|
| 1 | Urban | Digital STEAMIL module (experiment) | School 1 (n = 16 students, M = 9, F = 7) & school 2 (n = 20 students, M = 9, F = 11) |
| | | Conventional (control) | School 1 (n = 23 students, M = 9, F = 14) & school 2 (n = 18 students, M = 7, F = 11) |
| 2 | Rural | Digital STEAMIL module (experiment) | School 1 (n = 8 students, M = 3, F = 5) & school 2 (n = 23 students, M = 11, F = 12) |
| | | Conventional (control) | School 1 (n = 14 students, M = 9, F = 5) & school 2 (n = 20 students, M = 6, F = 12) |

**Table 3.** Indicators of mathematical literacy components

| Mathematical literacy competence | Literacy indicator |
|---|---|
| Mathematics thinking and reasoning | Apply deductive or inductive thinking in solving problems |
| Mathematical argumentation | Problem-solving in heuristics |
| Modeling | Create a mathematical model of the given problem |
| Problem-solving | Able to determine the required settlement strategy |
| Representation | State the problem with a picture, graph, or diagram |
| Communication | Convey in writing, concrete, pictures, or graphics |

**Table 4.** Mathematical literacy scores by treatment group

| Group | Digital STEAMIL module | | | | Conventional | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | $X_{max}$ | $X_{min}$ | Standard deviation | Mean | $X_{max}$ | $X_{min}$ | Standard deviation |
| Rural | 57.70 | 85.00 | 40.00 | 15.60 | 48.17 | 71.67 | 33.33 | 7.37 |
| Urban | 74.10 | 93.33 | 40.00 | 13.49 | 67.04 | 80.00 | 41.67 | 10.60 |

**Table 5.** Results of normality test (Shapiro-Wilk test)

| Group | Statistic | Significance | Information |
|---|---|---|---|
| Digital STEAMIL–rural | .902 | .065 | Normal |
| Digital STEAMIL–urban | .958 | .078 | Normal |
| Conventional–rural | .896 | .055 | Normal |
| Conventional–urban | .925 | .131 | Normal |

data were analyzed through descriptive statistics and validated using inferential statistical tests. The data were analyzed through descriptive statistics and validated using inferential statistical tests. To answer the questions in this research, financial statistical tests were carried out, namely univariate tests (ANOVA) and follow-up tests (LSD). Prior to this ANOVA analysis, the data underwent two assumption tests (normality and homogeneity tests). All analyses were carried out using SPSS software using a confidence level of 95% and a hypothesis acceptance criterion if the significance was more than alpha (.05).

## RESULT AND DISCUSSION

### Description of Research Data

The main aim of this research is to analyze differences in average students' mathematical literacy abilities based on different approaches (digital STEAMIL module vs. conventional), different student characteristics (urban vs. rural; male vs. female; and level of the Internet access). As discussed in the theoretical framework, prior research highlights the positive impact of STEAM-based learning and inquiry methods on students' mathematical skills. However, this study specifically focuses on the effectiveness of the digital STEAMIL module in enhancing mathematical literacy across different geographical contexts (urban vs. rural).

Two instructional approaches were employed: the digital STEAMIL module and conventional methods of teaching, both implemented in rural and urban schools. The study aimed to evaluate the effect of the digital STEAMIL module relative to traditional, teacher-led instruction. To measure the impact of these approaches, post-tests were administered to assess students' mathematical literacy levels. A summary of the descriptive statistics for each group is provided in **Table 4**.

The data in **Table 4** indicate that the highest average mathematical literacy score was achieved by the urban group taught with the digital STEAMIL module, with a mean of 74.10. In comparison, the rural group using the same module scored an average of 57.70. However, in learning using conventional methods we see that in rural schools the average score is 48.17 and higher in urban schools, namely 67.04. The distribution of the maximum scores in each class is the highest in urban schools using the digital STEAMIL module. Meanwhile, the highest standard deviation was in the group using the digital STEAMIL module in both rural and urban schools. This means that in this treatment group, the students' abilities after using the module were heterogeneous.

These results suggest that students in urban schools generally perform better in mathematical literacy than their rural counterparts. Similar trends were observed within the groups receiving conventional instruction. The statistical difference between these groups was further examined using hypothesis testing. The next section presents the results of the assumption testing that preceded the main statistical analyses.

### Assumption Testing Results

Before performing the main data analysis to address the RQs, several assumptions were tested to ensure the validity of the statistical methods used. Specifically, normality and homogeneity tests were conducted. The normality of the data was evaluated using the Shapiro-Wilk test, as the sample size for each treatment group was fewer than 50 participants (Mishra et al., 2019). The results are presented in **Table 5**.

As shown in **Table 5**, all significance values exceed the alpha threshold of .05, indicating that the data are normally distributed (Özgü et al., 2018). Thus, it can be concluded that all treatment groups meet the assumption of normality. The second assumption tested was the homogeneity of variances, which ensures that the variability across groups is consistent. Levene's test was applied to assess homogeneity, with the results summarized in **Table 6**.

The data analysis presented in **Table 6** shows that the significance values for all groups exceed .05, indicating that the assumption of homogeneity has been satisfied. With both the normality and homogeneity assumptions met, the data is suitable for inferential statistical analysis to address the RQs. The following sections present the analysis of each RQ using the ANOVA test.

**Table 6.** Result of homogeneity test (Levene's test)

| Concept | Group | Levene statistic | Significance | Information |
|---|---|---|---|---|
| Mathematical literacy | Digital STEAMIL module (urban)<br>Digital STEAMIL module (rural) | .876 | .068 | Homogeneous |
| | Conventional approach (urban)<br>Conventional approach (rural) | .831 | .057 | Homogeneous |

**Table 7.** Descriptive of differences in mathematical literacy (digital STEAMIL module vs. conventional)

| (Digital STEAMIL module vs. conventional) | Mean | Standard deviation | N |
|---|---|---|---|
| Digital STEAMIL module | 65.90 | 16.94 | 73 |
| Conventional | 57.68 | 11.73 | 69 |
| Total | 59.65 | 15.93 | 142 |

Note. Dependent variable: Mathematical literacy

**Table 8.** Tests of between-subjects effects (digital STEAMIL module vs. conventional)

| Source | Type III sum of squares | df | Mean square | F | Significance |
|---|---|---|---|---|---|
| Corrected model | 5,768.257[a] | 1 | 5,768.257 | 26.899 | .000 |
| Intercept | 501,782.364 | 1 | 501,782.364 | 2,339.919 | .000 |
| Treatment (digital STEAMIL module) | 5,768.257 | 1 | 5,768.257 | 26.899 | .000 |
| Error | 30,022.201 | 140 | 214.444 | | |
| Total | 541,009.256 | 142 | | | |
| Corrected total | 35,790.458 | 141 | | | |

Note. [a]$R^2$ = .161 (adjusted $R^2$ = .155) & Dependent variable: Mathematical literacy

### RQ1. Comparison of Mathematical Literacy (Digital STEAMIL module vs. Conventional Learning)

RQ1 focuses on the average difference in students' mathematical literacy abilities between those using digital STEAMIL modules and students taught via conventional methods. This analysis was carried out based on the scores from the mathematical literacy post-test for each treatment group. In answering questions based on the data obtained, it was analyzed using the univariate test (ANOVA). The results of descriptive analysis (ANOVA test output) of differences in literacy abilities in each treatment are in **Table 7**.

As illustrated in **Table 7**, there is a real difference in the average score of mathematical literacy abilities between students using the digital STEAMIL module and conventional learning classes. Data shows the average score for the digital STEAMIL module group is 65.90, while the average score for the conventional class is only 57.13. Standard deviation studies show that classes with digital learning STEAMIL modules are larger than conventional classes. This means that the diversity of abilities in the class is higher (heterogeneous), indicating greater variability in student abilities, compared to more consistent scores in the control group (conventional method).

These descriptive statistics suggest that students exposed to the digital STEAMIL module approach demonstrate higher levels of mathematical literacy than those taught through conventional instruction. However, to confirm whether this difference is statistically significant, an ANOVA test was conducted, with the results presented in **Table 8**.

As shown in **Table 8**, tests of between-subjects effects have a significance value of 0.000 (less than alpha, .05). This means a significant difference in students' mathematical literacy abilities between learning using the digital STEAMIL module and conventional learning. This difference shows that the digital STEAMIL module has an impact on mathematical literacy skills compared to conventional classes. What is proven by the descriptive test results is that the average mathematical literacy ability of students in this class is higher. From the test results, it can be seen that the R-squared ($R^2$) value is 0.161, which means the influence given is 16.10%.

In this research, we also show a comparison of the average percentage of students' mastery of each indicator of literacy ability. Student mastery in each class shows that learning with digital STEAMIL module is higher than conventional ones (**Figure 1**).

Based on both the descriptive and inferential analyses, it can be concluded that the digital STEAMIL module approach has a significantly greater impact on students' mathematical literacy than traditional teaching methods. These findings highlight the effectiveness of the digital STEAMIL module in enhancing mathematical literacy, particularly when compared to conventional learning approaches.

In this, we found differences in various components between learning with the digital STEAMIL module and conventional learning. Various aspects support students' literacy skills better. Using technology in teaching materials that have been designed is one of the ways to support students.

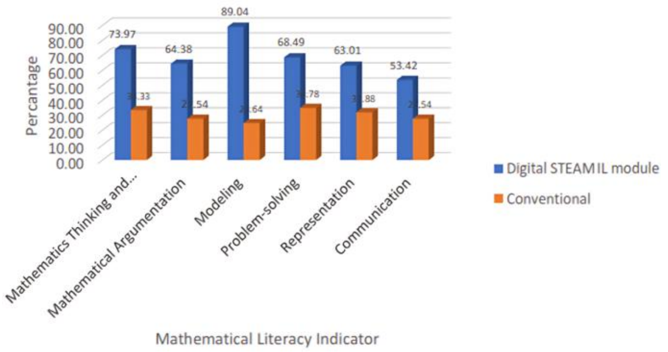


**Figure 1.** Descriptive mathematical literacy based on indicators (Source: Authors' own elaboration)

Technology appropriately used as a learning medium positively impacts students' understanding of concepts. Through technology-based media, learning barriers can be overcome (Drigas & Pappas, 2015). The use of technology designed as a STEAM inquiry module in this research makes it easier for students to understand mathematical concepts. In this module, we use technology such as video for concept orientation, generally conveyed in writing, interactive learning activities, and interactive exercises. Mathematical content is better conveyed when using visuals (video) so that the emphasis of initial concepts on students is more meaningful.

The findings of this research are supported by several previous studies that found that STEAM-based learning impacted literacy skills (Twiningsih & Elisanti, 2021). Students can relate everyday experiences to real life (Pasaribu & Suyanto, 2020). So, STEAM learning is very similar to mathematical literacy. Literacy development with the STEAM approach can occur because students can better find answers to problems (Long & Davis, 2017). Especially real problems that are solved through the mathematical modeling stage, the ability to solve problems (Naufal et al., 2024). In terms of increasing literacy, digital-based learning with STEAM plays a significant role in increasing elementary school students' numeracy literacy (Hidayanthia et al., 2024).

We look at the aspects of Inquiry integrated with STEAM project activities, guiding students to discover the concepts being studied for themselves. We found different things when students carried out projects through investigations designed in the module, where students tended to be more focused through investigation activities. Presenting investigative activities through STEAM projects to elementary school students may be new, However, this research supports active students in understanding the concepts that have been designed in the module. Previous research findings also found that literacy learning in elementary school students was more successful than in middle school (Afkhami et al., 2012). Even though they tend not to be used to connecting mathematics with the context of everyday life (Siregar et al., 2020).

**Figure 2.** Student activities in the STEAM-Inquiry project in the module (Source: Authors' own elaboration)

Projects in STEAM are inquiry-based in the use of modules to support student activities in understanding concepts. Investigative activities encourage differentiated learning for students (Laksana et al., 2019), and effective material explanations (Gillies, 2023). This is the case with student activities in STEAM projects in learning where they are interested and enthusiastic about learning. This is the opinion of Yıldız and Demirci (2021), who state that STEAM modules that are integrated with research support students in construction. In this activity, the emphasis is on instilling mathematical concepts at each activity stage so that students can learn meaningfully. We exemplify student activities in the STEAM project in **Figure 2**.

In **Figure 2**, it can be seen that students are enthusiastic about implementing the STEAM-Inquiry project. The mathematical concepts applied are fractions (making avocado juice) and spatial concepts (arranging towers). This is good for elementary school students so that learning becomes meaningful and student literacy also increases. This activity of students in this project is also done to understand the concept of the material in the module.

### RQ2. Comparison of Mathematical Literacy (Urban vs. Rural Schools)

RQ2 explores differences in students' mathematical literacy in urban and rural schools. In answering this question, data analysis was carried out on students' literacy ability data from each class (urban vs. rural). Analysis was carried out using the ANOVA test with descriptive average difference results in **Table 9**.

The descriptive analysis reveals a noticeable difference in average mathematical literacy scores between urban and rural schools. Students in urban schools achieved an average score of 65.06, which is higher than the average score of their rural counterparts (53.23). These results show descriptively that there are differences between these two groups. To prove this difference, a financial analysis was carried out using the

**Table 9.** Descriptive differences in mathematical literacy (urban vs. rural)

| (Urban vs. rural) | Mean | Standard deviation | N |
|---|---|---|---|
| Urban | 65.06 | 15.12 | 77 |
| Rural | 53.23 | 14.51 | 65 |
| Total | 59.65 | 15.93 | 142 |

Note. Dependent variable: Mathematical literacy

**Table 10.** Tests of the effects of between-subjects effects (urban vs. rural school)

| Source | Type III sum of squares | df | Mean square | F | Significance |
|---|---|---|---|---|---|
| Corrected model | 4,935.106[a] | 1 | 4,935.106 | 22.392 | .000 |
| Intercept | 493,236.855 | 1 | 493,236.855 | 2,237.964 | .000 |
| Demography (urban vs. rural) | 4,935.106 | 1 | 4,935.106 | 22.392 | .000 |
| Error | 30,855.352 | 140 | 220.395 | | |
| Total | 541,009.256 | 142 | | | |
| Corrected total | 35,790.458 | 141 | | | |

Note. [a]$R^2$ = .138 (adjusted $R^2$ = .132) & Dependent variable: Mathematical literacy

**Table 11.** Results of tests of between-subjects effects from each treatment

| Source | Type III sum of squares | df | Mean square | F | Significance |
|---|---|---|---|---|---|
| Corrected model | 12,054.944[a] | 3 | 4,018.315 | 23.363 | .000 |
| Intercept | 484,646.983 | 1 | 484,646.983 | 2,817.773 | .000 |
| **Treatment** | **12,054.944** | **3** | **4,018.315** | **23.363** | **.000** |
| Error | 23,735.514 | 138 | 171.996 | | |
| Total | 541,009.256 | 142 | | | |
| Corrected total | 35,790.458 | 141 | | | |

Note. [a]$R^2$ = .337 (adjusted $R^2$ = .322) & Tests of between-subjects effects

results of tests of between-subjects effects from the ANOVA test in **Table 10**.

The ANOVA test results in **Table 10** provide information that the test results for differences in mathematical literacy abilities (urban vs. rural) have a significance value of .000 (less than .05). These results prove that there are differences in students' mathematical literacy abilities between urban and rural schools. The findings suggest that students in urban schools exhibit higher mathematical literacy compared to those in rural schools after learning with digital STEAMIL modules. The results of this test show that mathematical literacy skills in urban schools are higher than in rural areas, as shown by the average score with an $R^2$ value of .138 (giving an influence of 13.80%).

In this research study, we also analyzed the impact of which treatment had a greater influence on mathematical literacy abilities. In carrying out this research, four treatment groups were previously described (rural-digital STEAMIL module; rural-conventional; urban-digital STEAMIL module; urban-conventional). To test the differences between these four groups, univariate analysis (ANOVA test) was carried out with descriptive statistical results in **Table 11**.

Based on **Table 11**, for treatment, the significance value is .000 (less than 0.05) which means there are differences between groups (rural-digital STEAMIL module; rural-conventional; urban-digital STEAMIL module; urban-conventional) regarding mathematical literacy abilities. The effect given from the treatment carried out was 33.70% where the SPSS output showed that the value of $R^2$ = .337. The mean differences for each treatment group are depicted in **Figure 3**.

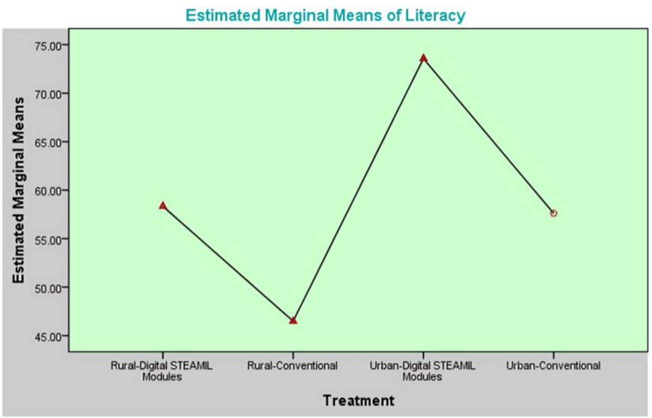


**Figure 3.** Estimated marginal means of literacy in each treatment class (Source: Authors' own elaboration)

In analyzing which groups provide the highest differences, further analysis is carried out using the LSD test in **Table 12**.

The results of the further test (LSD) in **Table 12** show that there are differences in literacy abilities in each treatment, marked by the asterisks (*). These results show that the treatment that has the highest difference compared to other groups is learning in urban schools using the digital STEAMIL module (urban-digital STEAMIL module). The results of the analysis in the mean difference column also show that the highest value is found in the difference with the conventional rural

**Table 12.** Post-hoc test (LSD) results of differences between the four treatment classes

| (I) Treatment | (J) Treatment | Mean difference (I-J) | Standard error | Significance |
|---|---|---|---|---|
| Rural-digital STEAMIL module | Rural-conventional | 11.8451* | 3.28501 | .000 |
| | Urban-digital STEAMIL module | -15.2293* | 3.07022 | .000 |
| | Urban-conventional | .7321 | 2.97382 | .806 |
| Rural-conventional | Rural-digital STEAMIL module | -11.8451* | 3.28501 | .000 |
| | Urban-digital STEAMIL module | -27.0744* | 3.30460 | .000 |
| | Urban-conventional | -11.1130* | 3.21524 | .001 |
| Urban-digital STEAMIL module | Rural-digital STEAMIL module | 15.2293* | 3.07022 | .000 |
| | Rural-conventional | 27.0744* | 3.30460 | .000 |
| | Urban-conventional | 15.9614* | 2.99545 | .000 |
| Urban-conventional | Rural-digital STEAMIL module | -.7321 | 2.97382 | .806 |
| | Rural-conventional | 11.1130* | 3.21524 | .001 |
| | Urban-digital STEAMIL module | -15.9614* | 2.99545 | .000 |

class. Apart from that, the mean difference value between the urban-digital STEAMIL module and vs. rural-digital STEAMIL module is 15.2293*. So, this analysis provides information that the application of the digital STEAMIL module has a different impact on mathematical literacy compared to the application of the digital STEAMIL module in rural groups.

The findings from the analysis of this research show that there are differences in the mathematical literacy abilities of students in urban and rural areas. Apart from that, the application of the digital STEAMIL module has a better impact on students' mathematical literacy in urban areas compared to schools in villages. Using the digital STEAMIL module in city schools is certainly easier compared to village areas due to the availability of technology in schools. Several studies support the finding that technology in urban areas is more developed (Jošic et al., 2022), while in village schools, it is still lacking. In terms of urban schools, they are also better in education (Ruth et al., 2023). The digital divide between urban and rural areas also affects teachers' ICT literacy and competence (Zhao, 2024). This research is supported by (Firdaus & Herman, 2017), which shows an increase in literacy skills based on different locations, namely rural, urban, and transition regions.

## RQ3. Comparison of Mathematical Literacy by Gender (Male vs. Female)

In addition to analyzing the impact of instructional methods and school location, this study also investigates whether gender differences affect mathematical literacy outcomes when using digital STEAMIL modules, and location. The purpose is to determine whether these modules have a differential impact on male and female students, which is crucial for identifying whether gender should be considered in the design and implementation of STEAM-based digital learning. Description of the average mathematical literacy abilities in each group in **Figure 4**.

The descriptive statistics in **Figure 4** indicate no significant difference in the average mathematical literacy scores between male and female students. Each

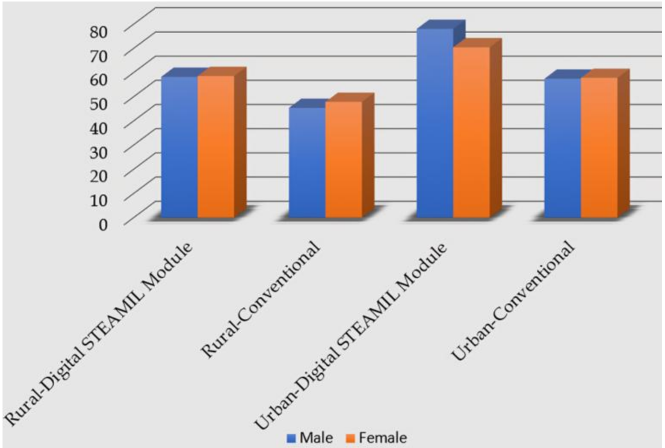


**Figure 4.** Descriptive statistics of mathematical literacy based on gender (male vs. female) (Source: Authors' own elaboration)

class does not have significant differences between female and male students. To prove this difference statistically, an ANOVA test was carried out with the results of the tests of the between-subjects effects in **Table 13**.

In **Table 11**, it is known that the results of testing literacy differences in terms of gender (male vs. female) obtained a significance value of .957 (more than .05). This means that this test rejects the hypothesis that there is a difference in average mathematical literacy in terms of gender. So, it was concluded that there was no difference in the average mathematical literacy abilities between men and women in each learning class. The results of the descriptive analysis show that in the digital STEAMIL module group, there is no difference in the average mathematical literacy ability between men and women. Therefore, there is no need for special adjustments or modifications based on gender when implementing this learning module.

The results of this study did not show a significant impact between male and female students. This research's results differ from the findings of research conducted by Ma et al. (2022), which found that STEAM learning had different impacts based on gender.

**Table 13.** Results of tests of between-subjects effects from each treatment class

| Source | Type III sum of squares | df | Mean square | F | Significance |
|---|---|---|---|---|---|
| Corrected model | .729[a] | 1 | .729 | .003 | .957 |
| Intercept | 502,627.979 | 1 | 502,627.979 | 1,966.148 | .000 |
| **Gender** | **.729** | **1** | **.729** | **.003** | **.957** |
| Error | 35,789.729 | 140 | 255.641 | | |
| Total | 541,009.256 | 142 | | | |
| Corrected total | 35,790.458 | 141 | | | |

Note. [a]$R^2$ = .000 (adjusted $R^2$ = -.007)

Research by Lavalle et al. (2024), found that female students were more motivated to use STEM video-based learning. In this research, the use of STEAM digital module teaching materials was carried out in villages and urban areas so that the distribution of male students in each area was different. However, the module uses Art elements so that it can link the material studied with cultural elements that exist in the area where students live. By using art elements, the concepts taught to students become more interesting and enjoyable (Lewandowska & Węziak-Białowolska, 2023).

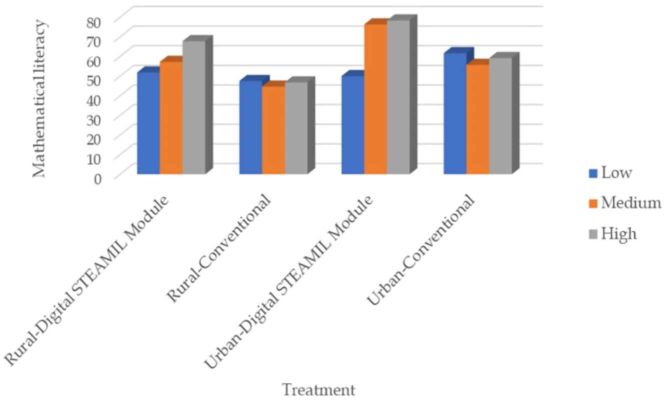


**Figure 5.** Descriptive statistics of mathematical literacy based on internet access levels in treatment (Source: Authors' own elaboration)

### RQ4. Comparison of Mathematical Literacy Based on Internet Access Levels (High, Medium, and Low)

This RQ examines how students' mathematical literacy outcomes, achieved through the use of digital STEAM-Inquiry modules, differ based on internet access levels. In addition to analyzing treatment type, school location, and gender, the study explored whether access to the internet influences students' literacy performance. Based on survey responses, participants were grouped into three categories: low, medium, and high levels of internet access. A descriptive summary of students' mathematical literacy scores across these categories is presented in **Figure 5**.

To determine whether the differences in mathematical literacy across the three internet access groups are statistically significant, ANOVA was conducted. The results of tests of the effects of between subjects are shown in **Table 14**.

The ANOVA test results indicate a p-value of 0.000 ($p < 0.05$), leading to the rejection of the null hypothesis. This confirms that there are statistically significant differences in students' mathematical literacy scores based on their internet access levels. To identify which groups differ from one another, a post-hoc test (LSD) was performed using SPSS. The results are summarized in **Table 15**.

**Table 14.** Tests of the effects of between-subjects effects (the Internet access)

| Source | Type III sum of squares | df | Mean square | F | Significance |
|---|---|---|---|---|---|
| Corrected model | 6,486.517[a] | 2 | 3,243.258 | 15.384 | .000 |
| Intercept | 476,689.141 | 1 | 476,689.141 | 2,261.12 | .000 |
| **The Internet** | **6,486.517** | **2** | **3,243.258** | **15.384** | **.000** |
| Error | 29,303.941 | 139 | 210.820 | | |
| Total | 541,009.256 | 142 | | | |
| Corrected total | 35,790.458 | 141 | | | |

Note. [a]$R^2$ = .181 (adjusted $R^2$ = .169)

**Table 15.** Post-hoc test (LSD) results (the Internet access)

| (I) The Internet access | (J) The Internet access | Mean difference (I-J) | Standard error | Significance |
|---|---|---|---|---|
| Low | Medium | -8.0302* | 2.93255 | .007 |
| | High | -18.4382* | 3.33219 | .000 |
| Medium | Low | 8.0302* | 2.93255 | .007 |
| | High | -10.4079* | 2.98196 | .001 |
| High | Low | 18.4382* | 3.33219 | .000 |
| | Medium | 10.4079* | 2.98196 | .001 |

The post-hoc test (LSD) results in **Table 15** indicate significant differences between the internet access groups, marked by the asterisks (*). For instance, students with high internet access performed significantly better than those with medium and low internet access. The largest difference was observed between students with high and low internet access. The results of this data analysis show that there is a tendency that high internet access to have a higher average literacy ability. This makes it possible that students are more likely to look for learning resources on the internet.

Many previous studies support the idea that the intensity of technology access impacts students' skills, especially in using digital-based learning. The easier it is for students to access digital, the more motivation they will use teaching materials (Alim et al., 2022; Brutman et al., 2024). We found that the more often students access the internet, the easier it is for them to use digital modules. The comparison results of urban classes and rural classes show, ignorance in accessing teaching materials provides different motivation and lower understanding of concepts compared to advanced students (Kumar et al., 2022).

Many studies support the idea that technology-based learning has an impact on student abilities. Interactive teaching materials increase children's visualization literacy (Alper et al., 2017), have a positive impact on improving the quality of education (Latifah et al., 2020), and encourage mathematical literacy skills (Susanta et al., 2022). So when using interactive teaching materials, digital access capabilities are also required. The easier it is for students to access digital, the more motivation they will use teaching materials. This is supported by the opinion that previous studies support the idea that the intensity of technology access impacts students' skills, especially in using digital-based learning (Purnomo et al., 2024; Wagino et al., 2024).

## CONCLUSION

The research findings prove differences in students' mathematical literacy abilities based on learning approach (STEAM-inquiry vs. conventional), location (urban vs. rural), and internet access. However, mathematical literacy is the same between male and female students. Based on the analysis results, the mathematical literacy skills of learning with the digital STEAMIL module are higher than those of conventional learning. From a geographical perspective, using the STEAMIL module impacts mathematical literacy in urban schools compared to rural schools. Besides that, internet access has a different impact on literacy skills after using the STEAMIL module. As a suggestion, when using digital-based teaching materials, it is very necessary to pay attention to student's readiness in using technology and technology based on the school area.

### Limitations

This research has several limitations, the results of this research can only represent the influence of digital STEAMIL modules on elementary schools in the provinces of Bengkulu and South Sumatra. Apart from that, there is still a need to socialize with students regarding the use of digital modules before learning is carried out. A limitation of this research is that there is no pretest that students take directly so it cannot be described as an improvement in students' abilities after being given treatment. In addition, the sample in this study received existing groups so the number of samples was not the same between classes in each treatment observed.

**Author contributions: AS:** conceptualization, formal analysis, writing - original draft; **ES:** methodology, formal analysis, data collection; **R:** validation, supervision; **HS:** data analysis; **SrbA:** writing - review and editing. All authors agreed with the results and conclusions.

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**Ethical statement:** The authors stated that in collecting data this study involved elementary school students in Indonesia. In collecting data, researchers conducted confirmation and permission through institutions in stages. Before collecting data, researchers conducted direct confirmation of the subject's consent for the availability of the subject. The authors further stated that this study has complied with the principles of scientific research ethics. The data collected in the study were conducted honestly, and transparently, and did not protect the privacy of the subjects and target schools.

**Declaration of interest:** No conflict of interest is declared by the authors.

**Data sharing statement:** Data supporting the findings and conclusions are available upon request from the corresponding author.

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