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Achieving Problem-Solving and Sustainability Competencies Through STEM–PBL Waste-Utilization Modules in Inclusive Mathematics Classrooms

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Abstract: This study investigates the achievement of a STEM–Problem Based Learning (PBL) module on students' mathematical problem-solving and sustainability competencies within an inclusive classroom. The module centers on Social Arithmetic and integrates waste-utilization activities to promote meaningful, real-world learning aligned with Education for Sustainable Development (ESD). Designed for diverse learners, including students with mild learning difficulties, the module incorporates scaffolding, hands-on tasks, multimodal representations, and flexible grouping to ensure equitable access to learning. Using a descriptive one-group design, students engaged in STEM–PBL tasks that, although not explicitly framed as ESD instruction, naturally fostered sustainability awareness and responsible environmental behaviors. Expert-validated instruments assessed mathematical problem-solving and sustainability achievement, with adaptations to support inclusive education principles. Data were analyzed using the Respondent Achievement Level (RAL) method. The findings show that students achieved high levels of performance in both domains. The learning process also encouraged active involvement in waste-utilization projects such as creating decorative pots, ecobricks, paving blocks, reusable bags, and producing animal feed from organic waste using maggots. Activities designed to accommodate students with varied abilities. These results indicate that STEM–PBL modules can support problem-solving skills while simultaneously nurturing sustainability competencies in inclusive mathematics settings.

Keywords: Inclusive, STEM education, Problem solving, Sustainability

Introduction

Mathematics education in the 21st century demands a more meaningful, contextual, and real-life learning process (Mustafa, 2023; Rehman et al., 2024). Learning that solely emphasizes mastery of formulas and calculation procedures is no longer sufficient to equip students to face the complexity of global problems (Asare et al., 2025). In the Indonesian context, inclusive classrooms, where students with typical development learn together with peers who require special attention due to various limitations, also need to be supported with equitable access to technology and STEM-based learning opportunities. These classrooms demand instructional approaches that are adaptive, accessible, and capable of engaging diverse learners with different needs and

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learning profiles. Integrating technology and STEM concepts can help bridge learning gaps by providing multimodal representations, hands-on activities, and assistive tools that make abstract ideas more concrete and accessible for all students. Therefore, an integrative approach such as STEM (Science, Technology, Engineering, and Mathematics) is crucial. STEM-integrated learning refers to an approach that connects the four disciplines in a unified and contextual manner, allowing students to solve real-world problems through interdisciplinary thinking. Within this framework, Science guides students to explore natural phenomena and understand the properties of materials; Technology involves the use of tools, devices, and digital or manual techniques to support problem-solving; Engineering emphasizes designing, creating, and optimizing solutions or products; and Mathematics provides the analytical foundations for calculations, measurements, and quantitative reasoning. STEM not only strengthens mathematical conceptual understanding but also encourages students to think critically, creatively, and collaboratively while developing practical problem-solving skills that can be applied in everyday life (Bustamante-Mora et al., 2025; Henriksen, 2014; Sirajudin et al., 2021). One relevant topic to integrate with the STEM approach is Social Arithmetic, which is closely related to students' daily economic and social activities, such as buying and selling, profit, loss, discounts, and percentage calculations (Betty Heryuriani & Musdayati, 2020; Wangguway et al., 2020). However, Social Arithmetic is often taught conventionally with routine problems, limiting students' opportunities to connect concepts to real-life situations. Integrating STEM into Social Arithmetic can enrich the learning experience through meaningful, contextual, and project-based activities that foster active learning (Wangguway et al., 2020).

To address this need, a STEM-based e-module on Social Arithmetic with the context of waste utilization was developed. This module presents Social Arithmetic concepts in an integrated manner with STEM disciplines through project activities that directly engage students in waste management practices. In inclusive classrooms, where students with diverse abilities learn side by side, such project-based STEM activities provide multiple entry points for participation, allowing each student to contribute according to their strengths while still working toward shared learning goals. Students are guided to apply Science in understanding material properties of waste, Technology in utilizing simple tools for processing, Engineering in designing and producing useful products, and Mathematics in calculating costs, profits, and percentages. Although ESD principles are not delivered explicitly, the authentic waste-based projects naturally foster ESD-related competencies by encouraging responsible resource use, environmental awareness, and sustainable decision-making. Projects embedded in the module include creating eco-bricks, decorative pots, paving blocks, bags from recycled plastic, and animal feed from organic waste using maggots. These activities not only strengthen students' STEM-related understanding but also provide hands-on, differentiated learning experiences that are suitable for inclusive settings, enabling all learners, including those who require additional support, to actively participate and succeed. Through these activities, mathematics learning becomes more authentic, engaging, and connected to students' real lives, while simultaneously promoting sustainability awareness (Bustamante-Mora et al., 2025; Killpack & Melón, 2016). Here are module home page and an example of one of the activity pages in the module:

Figure 1. Home page and one of the modul activity pages

In addition to mathematical understanding, current education also aims to cultivate students' sustainability awareness and behaviors, encompassing the three pillars of sustainability: environmental, social, and economic (Colón-Flores et al., 2023; Ekamilasari et al., 2021). Environmental sustainability involves fostering students' responsibility for managing natural resources and reducing waste, which can be applied through activities such as creating eco-bricks, decorative pots, paving blocks, and animal feed from organic waste (Zulfa et al., 2025). Social sustainability focuses on supporting collaboration, communication, and social responsibility among students as they work together to plan, implement, and evaluate their projects (Colón-Flores et al., 2023). Economic sustainability emphasizes practical understanding of value creation, cost management, and resource utilization, enabling students to calculate production costs, selling prices, profits, and assess the economic feasibility of their projects (e Souza et al., 2024; Ekamilasari et al., 2021). These three dimensions of sustainability provide a holistic framework for integrating mathematical problem-solving with real-life, meaningful projects (Li, 2025).

Against this background, this study was conducted to analyze students' mathematical problem-solving and sustainability achievements through a STEM-based Social Arithmetic module in the context of waste utilization. In inclusive classrooms, where students with diverse abilities learn together, the integration of STEM with contextual sustainability issues provides opportunities for differentiated learning pathways that remain coherent within a shared project. By embedding environmental, social, and economic sustainability indicators into project-based learning, the module enables all students, including those who require additional support, to engage in hands-on, meaningful activities that accommodate varied learning needs. This research is therefore expected to provide both theoretical and practical contributions to the development of contextual and inclusive mathematics learning models that prepare students for the challenges of the 21st century while promoting sustainable behaviors.

Method

This study used a descriptive method to analyze students' mathematical problem-solving and sustainability achievements through the implementation of a STEM-based Social Arithmetic module within the context of waste utilization. The study subjects consisted of 30 junior high school students in Bogor, West Java, Indonesia, who had studied Social Arithmetic and participated in learning using the waste-based STEM module. The module was designed to integrate Social Arithmetic concepts with a STEM approach through a waste management project and was validated by experts. Its development followed the 4D model, consisting of four systematic stages. The Define stage identified learning needs, curriculum alignment, and relevant sustainability issues related to waste utilization. The Design stage involved constructing the module framework, selecting STEM–PBL learning activities, and mapping Social Arithmetic materials to real-world waste management contexts. In designing the module, special consideration was given to inclusive classroom settings, ensuring that activities were adaptable for students with diverse learning abilities. The module content and learning strategies were discussed and adjusted in collaboration with the classroom teacher to ensure relevance and feasibility for the students. During the Develop stage, the module was produced in e-module format, complemented with project instructions, worksheets, and visual guides; expert validation was conducted to ensure content accuracy, pedagogical feasibility, and alignment with STEM and sustainability goals. Finally, the Disseminate stage included limited implementation in the inclusive classroom to evaluate usability, accommodate diverse student needs, and gather student responses.

The module's content covered profit and loss, discounts, percentages, and price comparisons, all integrated with authentic project activities. For example, students calculated the production costs of decorative pots from plastic bottles, estimated the selling price of ecobricks, and analyzed profit margins for making concrete blocks or other recycled products. These activities enabled students to apply mathematical concepts while simultaneously cultivating sustainable attitudes and problem-solving skills.

The research instruments consisted of a mathematical problem-solving test and a sustainability test, both validated by experts. Validation focused on ensuring content accuracy, clarity, and alignment with the research objectives (Creswell & Creswell, 2018; Sugiyono, 2013). The expert validation results indicated that the instruments were in the very valid category based on the five-level criteria (very valid: $80\% < x \leq 100\%$; valid: $60\% < x \leq 80\%$; less valid: $40\% < x \leq 60\%$; invalid: $20\% < x \leq 40\%$; very invalid: $0\% \leq x \leq 20\%$). The material expert provided a score of 85%, the media expert 86%, and the STEM–ESD expert 82%, all of which fall within the very valid category. These results confirm that the instruments were appropriate for assessing students' mathematical problem-solving abilities and sustainability achievement.

Data collection was conducted through a final test at the end of the lesson. Data were analyzed using the Respondent Achievement Level (RAL) to determine student achievement categories (Rahmawati et al., 2023; Sugiyono, 2013). Thus, this study can demonstrate the extent to which students achieve problem-solving and sustainability through waste-reuse-based STEM modules. The following is a table of RAL categories:

Table 1. RAL categories

RAL Category	Score Range (%)
Excellent	90 – 100
Good	80 – 89
Fairly Good	65 – 79
Less Good	55 – 64
Poor	0 – 54

Results and Discussion

This study analyzes students' mathematical problem-solving and sustainability achievements through the implementation of a STEM-based Social Arithmetic module within the context of waste utilization. The study subjects were 30 junior high school students in Bogor, West Java, Indonesia, who had studied Social Arithmetic and participated in learning using the waste-based STEM module. Based on the results of a final test, the students' scores were as follows:

Table 2. Problem solving and sustainability test scores

Interval	Frequency (f)
41–50	1
51–60	1
61–70	1
71–80	8
81–90	10
91–100	9

The data in Table 2 reveal the distribution of students' test scores after engaging in the module-based learning. The scores ranged from 41 to 100, with most students achieving within the 71–100 interval. Specifically, one student scored between 41–50, one between 51–60, one between 61–70, eight between 71–80, ten between 81–90, and nine between 91–100. This distribution suggests that the majority of students demonstrated high achievement levels, with 27 out of 30 students (90%) scoring above 70. Such a pattern indicates not only a good mastery of mathematical problem-solving but also a growing awareness of sustainability principles embedded in the learning activities. To gain a more systematic understanding of student achievement, the data were analyzed using the Respondent Achievement Level (RAL) method. This approach transforms raw scores into categorized levels that represent students' mastery more meaningfully. The RAL method divides performance into categories such as very high, high, moderate, low, and very low, allowing the interpretation of data beyond mere numerical values. Applying this method to the results highlights that most students fall within the high and very high categories, affirming the role of the STEM-based approach.

From a pedagogical perspective, the results suggest that the integration of STEM and sustainability contexts into Social Arithmetic learning fosters deeper engagement and conceptual understanding. Through waste-based projects such as calculating the cost and profit of creating recycled products or analyzing savings from waste management students are encouraged to apply mathematical formulas in authentic, context-rich situations. The significant clustering of scores in the higher range (81–100) can also be interpreted as an indicator of high learning design and student motivation. The project-oriented tasks within the STEM module likely stimulated curiosity and active participation. Students may have felt a personal connection to the topic, as waste management is a visible and relatable issue in their local community. This emotional engagement supports cognitive processing, leading to better retention and transfer of mathematical concepts (Maqruf et al., 2024; Twomey & Westermann, 2018).

Furthermore, the integration of sustainability topics serves as a medium for value-oriented education. Mathematics becomes more than procedural computation; it becomes a means of contributing to social and environmental improvement. In inclusive classrooms, where students have diverse abilities and learning needs, this approach allows all learners to engage meaningfully with real-life problems. Students learn that mathematics can guide decision-making in daily life, such as budgeting, evaluating product costs, and managing

resources responsibly, with activities that can be adapted or scaffolded according to individual needs. This connection between numeracy and sustainability literacy exemplifies the dual outcomes of the STEM-based module: academic achievement and personal growth toward responsible citizenship. Analyzing the data through the RAL framework, it can be inferred that the mean achievement level falls within the "high" category, suggesting that most students, including those requiring additional support, demonstrated both conceptual understanding and contextual application ability. The small number of students in the lower intervals (below 70) may indicate differences in prior mathematical ability, learning pace, or engagement levels. Nevertheless, the distribution skewed toward higher performance emphasizes that the STEM-based module successfully accommodates diverse learners in inclusive classrooms through interactive and problem-based approaches. (Killpack & Melón, 2016; Zakirah & Widowati, 2024). These values were then analyzed using the Respondent Achievement Level (RAL) method and arranged in grouped tables to obtain a more systematic picture of student achievement.

Table 3. RAL and mean data processing

Score Interval	RAL Category	Frequency (f)	Persentation (%)	Mid-Score (x)	$f \times x$
41–50	Poor	1	3.3	45.5	45.5
51–60	Less Good	1	3.3	55.5	55.5
61–70	Fairly Good	1	3.3	65.5	65.5
71–80	Good	8	26.7	75.5	604
81–90	Excellent	10	33.3	85.5	855
91–100	Excellent	9	30	95.5	859.5
Total	—	30	100	—	2484.5

The data show the distribution of student scores on the final test after using the STEM-based Social Arithmetic module focused on waste utilization. The scores were grouped into intervals and classified according to the Respondent Achievement Level (RAL) categories: Poor, Less Good, Fairly Good, Good, and Excellent. A total of 30 students participated in the assessment.

From the table, it can be observed that most students achieved high-performance levels. Specifically, in the 41–50 interval, only 1 student (3.3%) fell into the Poor category, with a mid-score of 45.5. The 51–60 interval also included 1 student (3.3%) classified as Less Good, with a mid-score of 55.5. Similarly, the 61–70 interval had 1 student (3.3%) in the Fairly Good category, with a mid-score of 65.5. A significant proportion of students scored in the Good and Excellent categories. In the 71–80 interval (Good), 8 students (26.7%) achieved a mid-score of 75.5, reflecting solid mastery of the material. The 81–90 interval (Excellent) included 10 students (33.3%) with a mid-score of 85.5, and the 91–100 interval (also Excellent) had 9 students (30%) with a mid-score of 95.5. These results indicate that 63.3% of students reached the highest performance level (Excellent), while another 26.7% were classified as Good, demonstrating strong overall achievement.

The mean score of 82.82 was obtained by dividing 2484.5 by 30, thus indicating that overall, the students were in the good category, which confirmed good achievement in both problem solving and sustainability attitudes. Overall, the distribution illustrates that the STEM-based Social Arithmetic module performed well in supporting the achievement **of** students' mathematical problem-solving skills and their ability to apply sustainability concepts. The low frequencies in the Poor, Less Good, and Fairly Good categories indicate that almost all students were able to engage with the material successfully. The dominance of mid-scores in the Good and Excellent ranges also reflects the module's helps student in providing meaningful, real-life, and contextual learning experiences in line with several contextual module studies (Napfiah & K, 2024; Syarif & Achmad, 2020).

This success can be analyzed through the three main pillars of sustainability, which serve as indicators of sustainability performance: environmental, social, and economic. In the environmental aspect, the module encourages students to engage in waste utilization activities such as making ecobricks, decorative pots, paving blocks, and recycled plastic bags. These hands-on projects not only increase students' awareness of waste management and human impacts on ecosystems but also indirectly foster ESD-related competencies, particularly in developing environmentally responsible attitudes and sustainable decision-making. (Colón-Flores et al., 2023; Ekamilasari et al., 2021; Zulfa et al., 2025). The integration of these activities with the concept of Social Arithmetic allows students to apply mathematical principles practically in real-world contexts, in line with project-based learning theory, which emphasizes the authenticity and relevance of the material (Wangguway et al., 2020). Socially, these projects encourage collaboration, communication, and teamwork among students. In inclusive classrooms, where learners have diverse abilities and needs, such collaborative activities allow students to contribute according to their strengths while learning from their peers. During the

process, students learn to divide tasks, solve problems together, and value the contributions of all classmates, including those who may require additional support, thus achieving interpersonal skills, social awareness, and empathy. This supports the literature that suggests project-based learning can foster social skills and collective responsibility, demonstrating that the STEM-based module is particularly relevant for inclusive learning environments (Bustamante-Mora et al., 2025; Han et al., 2015; Rehman et al., 2024). Meanwhile, the economic aspect is reflected in activities that transform waste into economically valuable products, enabling students to understand the concepts of added value, resource efficiency, and cost management. The application of Social Arithmetic in a sustainable economic context provides students with practical insights into entrepreneurship and responsible resource management (Betty Heryuriani & Musdayati, 2020; OECD, 2018).

The predominance of high scores in the excellent category indicates that students not only understand the theory but are also able to apply it in complex situations that require creativity, collaboration, and critical thinking (Fasha Alsya'bi et al., n.d.). This STEM-based learning approach, with its real-world context, achieve students' intrinsic motivation and creates authentic learning experiences (Cantlon et al., 2024; Roberts et al., 2018). By integrating the three pillars of sustainability, this module successfully develops holistic competencies, where cognitive, affective, and psychomotor aspects develop simultaneously (e Souza et al., 2024; Primahardani et al., 2024; Vargas-Santander et al., 2023). This finding aligns with 21st-century educational principles that emphasize the development of critical, creative, and collaborative thinking skills, as well as global awareness of environmental and social issues (Colón-Flores et al., 2023; Ekamilasari et al., 2021; Li, 2025).

Conclusion

Based on the RAL analysis, the STEM-based Social Arithmetic module with a waste utilization context support students' mathematical problem-solving skills and sustainability awareness. The average score of 82.82 in the good category indicates strong conceptual understanding and application. In inclusive classrooms, the module proved relevant and adaptable, allowing students with diverse abilities to engage meaningfully in learning activities. The module integrated the three pillars of sustainability: environmental, social, and economic, while indirectly supporting ESD competencies through responsible waste management, collaborative activities, and basic economic analysis of recycled products. This integration strengthened not only cognitive abilities but also ecological awareness, social responsibility, and practical economic understanding for all learners. Overall, the module offers an innovative and inclusive approach to 21st-century mathematics learning by combining academic competence, life skills, and sustainable values aligned with ESD, making it particularly suitable for classrooms with diverse learning needs.

Recommendations

A key recommendation is to expand the implementation of this STEM-based Social Arithmetic module to a wider range of classroom contexts to further assess how it supports learning in inclusive environments. Teachers are encouraged to apply differentiated learning strategies and integrate sustainability-focused activities so that students with varied abilities can engage meaningfully. The module can be strengthened by adding supportive digital tools, richer project-based tasks, and flexible assessment options to achieve participation and deepen students' sustainability awareness. Further research is needed to examine long-term impacts on mathematical problem-solving skills and broader ESD competencies.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPESS journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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