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The Effectiveness of an SDG-Based Inclusive STEM Module on Science Process Skills of Slow Learner Students in Peatland Areas

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Abstract: This study aims to evaluate the effectiveness of an inclusive STEM module based on the Sustainable Development Goals (SDGs) in improving science process skills (SPS) among slow learner students in a peatland region. A quasi-experimental pretest-posttest control group design was employed with 78 Grade 8 slow learners from SMP Negeri 1 Pemulutan Barat, South Sumatra. The module, developed using the ADDIE model, focused on water filtration and peatland water quality within the context of SDG 6 (Clean Water and Sanitation). The core science topics covered included pH measurement, mechanical filtration, separation of mixtures, and colloidal properties of peat water. It was validated by experts in content, pedagogy, and inclusivity. Data were analyzed quantitatively using independent t-tests, normalized gain (N-Gain), and effect size (Cohen's d), as well as qualitatively through classroom observations and semi-structured interviews. Results revealed that the experimental group achieved a mean N-Gain of 0.79 (high category), compared to 0.42 (medium category) for the control group. Statistical analysis indicated a significant difference between the groups ($t = 5.68$; $p < 0.001$; Cohen's $d = 1.28$). Qualitative findings further demonstrated that students reported increased confidence and motivation, attributing these improvements to the module's use of visual illustrations, locally relevant contexts, and scaffolded instructions. These findings suggest that an inclusive, SDG-based STEM module is effective in improving SPS among slow learner students. This study contributes to the growing body of literature on inclusive STEM education by illustrating how integrating the SDGs within a local ecological context can foster equitable and meaningful science learning.

Keywords: Inclusive STEM; Instructional module; Science process skills; Slow learners; Sustainable Development Goals (SDGs)

Introduction

Twenty-first-century education demands the development of critical thinking, creativity, collaboration, and communication skills (Salvador-Garcia et al., 2025). A foundational component in fostering these competencies is science process skills (SPS), which encompass abilities such as observation, inference, hypothesis formulation, experimentation, and data interpretation (Özalp, 2023). Unfortunately, these skills remain underdeveloped in Indonesia, particularly in South Sumatra, as evidenced by suboptimal science literacy levels among lower secondary school students (Andriani et al., 2018).

The STEM (Science, Technology, Engineering, and Mathematics) approach is widely regarded as an

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effective strategy for cultivating both 21st-century skills and SPS (Nipyrakis et al., 2024; Zakiyah et al., 2019). However, the implementation of STEM in Indonesia continues to face significant challenges regarding inclusivity, especially for slow learner students who are often inadequately accommodated in conventional instructional settings (Listiawati et al., 2023). Without intentional instructional modifications, students with slower learning paces risk falling further behind in developing scientific competencies (Arafat et al., 2024). Research indicates that slow learners benefit from differentiated approaches that integrate instructional scaffolding, multimodal representations, and active engagement within authentic contexts (McKee et al., 2023).

In peatland regions of Indonesia, a relevant local context is water quality—an issue directly aligned with Sustainable Development Goal (SDG) 6 (Clean Water and Sanitation) and SDG 4 (Quality Education) (Williams, 2020; Zguir et al., 2021). Peat water in South Sumatra is typically acidic (pH 3–5), dark-colored due to humic substances, and contains suspended colloids, making it unsuitable for direct consumption. Integrating SDG-related themes into science instruction lends real-world meaning to abstract scientific concepts (Akhsan et al., 2023) and encourages students to make meaningful connections between scientific knowledge and global sustainability challenges (Karrow & Fazio, 2021). Place-based learning approaches of this nature have been shown to enhance intrinsic motivation and conceptual retention, particularly among students from marginalized backgrounds (Chu et al., 2022). Furthermore, inclusively designed STEM instruction—accounting for cognitive diversity, linguistic needs, and accessibility—can foster equitable and participatory learning environments (Afriana et al., 2016; Kim & Kim, 2022).

Although numerous studies have explored STEM and the SDGs separately (Chang et al., 2024; Nipyrakis et al., 2024), the tripartite integration of STEM, SDGs, and inclusive principles specifically tailored for slow learners within ecologically specific contexts—such as peatland areas—remains notably underexplored. Moreover, the application of systematic instructional design models, such as ADDIE (Analysis, Design, Development, Implementation, Evaluation), in developing such inclusive modules has rarely been documented. This research fills this gap by presenting a rigorously developed and evaluated module that explicitly links local environmental issues (peat water purification) with global sustainability goals (SDG 6) while applying Universal Design for Learning (UDL) principles for slow learners.

Therefore, this study seeks to answer two central questions: (1) How effective is an inclusive, SDG-based STEM module in enhancing the science process skills of slow learner students? and (2) How do students and teachers perceive the accessibility and contextual relevance of the module?

Method

This study employed a mixed-methods approach within a quasi-experimental pretest-posttest control group design, integrated with the ADDIE (Analysis, Design, Development, Implementation, Evaluation) instructional design model to develop and evaluate an inclusive STEM module focused on enhancing science process skills (SPS) among slow learner students in a peatland region (Dewi et al., 2024). The research was conducted at SMP Negeri 1 Pemulutan Barat, Ogan Ilir Regency, South Sumatra, involving 78 Grade 8 students identified as slow learners. The identification process combined academic performance data (science scores below 70 over two consecutive semesters) with a standardized cognitive ability assessment using Raven's Progressive Matrices. Students scoring between IQ 70 and 85 were classified as slow learners, ensuring alignment with established educational psychology criteria. After screening, participants were divided into an experimental group (n = 36) and a control group (n = 42). To ensure baseline equivalence in SPS proficiency, a matching-by-means technique was applied based on their pretest scores.

The development of the inclusive STEM module followed the five phases of the ADDIE model (Atika et al., 2025; Deprizon et al., 2025). In the Analysis phase, a comprehensive needs assessment was conducted through interviews with science teachers and classroom observations to understand the learning challenges faced by slow learners in the context of local environmental issues, particularly peatland water quality. During the Design phase, a concept map was constructed to integrate core science topics—such as pH measurement, mechanical filtration, separation of mixtures, and colloidal properties of peat water—with Sustainable Development Goal 6 (Clean Water and Sanitation) and key science process skills. The Development phase involved creating a draft module that incorporated visual illustrations, simplified language, step-by-step instructions, and collaborative inquiry tasks aligned with Universal Design for Learning (UDL) principles. The module was validated by three experts in content, pedagogy, and inclusivity, yielding a Content Validity Index (CVI) of 0.91. Feedback led to revisions, including enhanced pictorial guides and color-coded activity sheets. A pilot test was then conducted with 10 slow learner students outside the main sample to assess readability, clarity, time allocation, and practical feasibility, resulting in further refinements before full implementation.

The intervention consisted of four 90-minute inquiry-based sessions delivered over two weeks. The experimental group engaged with the inclusive, SDG-based STEM module through hands-on activities: (1) investigating the physical and chemical properties of peatland water (e.g., pH, turbidity, odor), (2) designing a multi-layer water filter using locally available materials such as sand, gravel, activated charcoal, and cloth, (3) testing the filter's effectiveness by comparing input and output water samples, and (4) reflecting on how clean water access relates to community health and global sustainability (SDG 6). Meanwhile, the control group received conventional instruction using standard textbooks and worksheets aligned with the national curriculum. Data collection utilized both quantitative and qualitative instruments. An SPS test, developed based on Özalp (2023) and validated by experts (validity > 0.80; Cronbach's Alpha = 0.87), was administered as a pretest one week before the intervention and as a posttest one week after its completion. Qualitative data were gathered through participant observation using a structured checklist, semi-structured interviews with 12 purposively selected students and two science teachers, and photo/video documentation during lessons.

Quantitative data were analyzed using IBM SPSS version 26. Normality was tested with Shapiro-Wilk, and homogeneity of variance was assessed using Levene's test. Normalized gain (N-Gain) scores were calculated to measure relative improvement in SPS, and an independent-samples t-test was performed to compare the gains between groups (Mumba et al., 2023). Effect size was determined using Cohen's. For qualitative data, thematic analysis was conducted through open coding and constant comparison, supported by data triangulation to enhance credibility and trustworthiness. This rigorous methodological framework ensured both the validity of the findings and the practical relevance of the module for inclusive science education in ecologically unique contexts.

Result and Discussion

Baseline equivalence was confirmed: no significant difference in pretest SPS scores ($t = 0.15$, $p = 0.883$) or variance (Levene's test, $p = 0.416$). Mean pretest scores were 25.19 (experimental) and 24.67 (control).

After the intervention, the experimental group's posttest mean rose to 84.53, while the control group reached 56.17. The experimental group showed a high normalized gain (N-Gain = 0.79), whereas the control group showed moderate improvement (N-Gain = 0.42). An independent t-test confirmed a statistically significant difference ($t = 5.68$, $p < 0.001$), with a large effect size (Cohen's $d = 1.28$), indicating substantial practical impact.

Table 1. Comparison of Pretest, Posttest, and N-Gain Scores of Science Process Skills Among Slow Learner Students

Group	N	Mean Pre Test	Mean Post Test	Mean N Gain	N Gain Category
Experimental	36	25.19	84.53	0.79	High
Control	42	24.67	56.17	0.42	Medium

Note: N-gain calculated using (Hake, 1998) *Values ≥ 0.7 = high, 0.3–0.7 = medium, < 0.3 = low.*

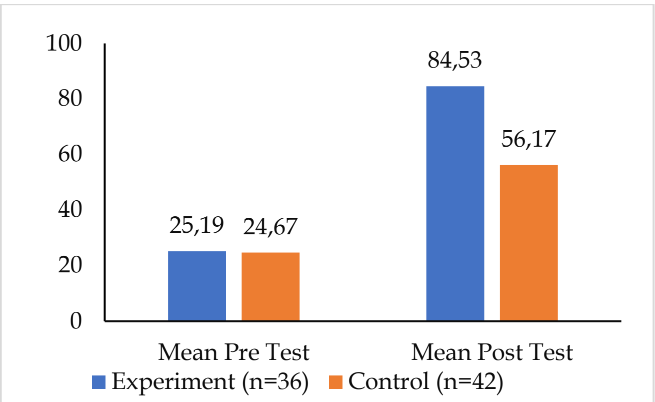

Figure 1. Comparison of mean pretest and posttest scores of science process skills between the experimental group and the control group.

Qualitative findings revealed three key themes: The module is easy to understand because it includes many pictures and clear step-by-step instructions." Students appreciated visual aids and structured guidance; now I know that peat water can be cleaned by ourselves." The local context empowered students, increasing relevance and ownership; "I'm not shy to ask questions because we work together on everything." Collaborative tasks reduced anxiety and promoted participation.

Teachers observed increased engagement, confidence in expressing ideas, and improved task completion rates. The high N-Gain and large effect size align with prior studies showing that hands-on STEM activities significantly boost SPS (Çoruhlu et al., 2023; Irwanto, 2023; Rampean et al., 2025). The integration of inquiry-based learning allowed students to practice observing, measuring, and experimenting in authentic contexts—key components of SPS development (Joseph & Abraham, 2023; Özalp, 2023).

Furthermore, the module's success can be explained through Universal Design for Learning (UDL) theory (McKee et al., 2023). Visual illustrations and simplified text addressed representation barriers; step-by-step guides supported action and expression; collaborative tasks enhanced engagement—critical for slow learners with limited working memory and processing speed.

Compared to similar studies, the effect size (d = 1.28) exceeds those reported by Yenice & Uzun (2024) (d = 0.85) in inclusive science interventions, suggesting that combining local ecological relevance (peat water) with global goals (SDG 6) amplifies motivation and learning outcomes. This supports place-based sustainability education frameworks (Karrow & Fazio, 2021), where connecting science to students' lived experiences fosters deeper engagement.

The focus on water filtration—a tangible, community-relevant problem—allowed students to see immediate applications of science, reinforcing conceptual understanding and self-efficacy. This finding echoes Chu et al. (2022), who found that place-based contexts improve affective and cognitive outcomes in marginalized learners.

Conclusion

This study demonstrates that an inclusive, SDG-based STEM module centered on water filtration and peatland water quality (covering pH, filtration, and colloid separation) is highly effective in improving science process skills among slow learner students in peatland areas. This is evidenced by a high normalized gain (0.79), a statistically significant difference compared to the control group (t = 5.68, p < 0.001), and a large practical impact (Cohen's d = 1.28). Qualitative data further confirm that the module enhances student confidence, motivation, and collaborative engagement through its use of visual scaffolds, local context, and inclusive design. The findings support the integration of place-based sustainability themes into inclusive STEM education as a powerful strategy for achieving equitable and meaningful science learning. Despite its contributions, this study has several limitations. First, the sample was drawn from a single school in a peatland region, limiting generalizability. Second, although multiple criteria were used, the identification of slow learners did not include formal psychological diagnosis. Third, the quasi-experimental design, despite matching procedures, may still carry some selection bias due to the lack of full randomization. Future research should replicate this study in diverse geographical and educational settings, extend the module to other SDGs (e.g., SDG 13 on Climate Action), and develop a digital interactive version to increase accessibility. Teachers are encouraged to adapt the module for different grade levels, while school administrators and policymakers should support professional development and funding for inclusive, context-based STEM materials.

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Author Contributions

Kistiono: Conceptualization, methodology, Muhammad Yusup: formal analysis Sudirman: writing—original draft preparation, Kiki Ayu Winarni: Collecting data, Putri Angelina : project administration

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Conflicts of Interest

The authors declare no conflict of interest.

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