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Original Article

STEM-Based Microgreen Learning Media to Enhance Senior High School Students' Science Process Skills

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Abstract: Science process skills are crucial in biology education and benefit from experiential, inquiry-based approaches. However, biology learning often remains abstract and lacks subject-specific media. This study investigated the effectiveness of STEM-based learning using biodegradable microgreen seed paper to enhance eleventh-grade students' science process skills and learning responses in plant growth and development. Using a one-group pretest–posttest design (n = 36), students engaged in scientific inquiry, engineering-based design of seed paper, and technology-assisted observation. Science process skills were assessed via essays, and student responses via a Guttman-scale questionnaire. Data analysis with N-gain and the Wilcoxon test showed significant improvement in science process skills (pretest mean = 63.19, posttest mean = 89.03, N-gain = 0.71, Z = −5.248, p < 0.05) and very positive student responses (97%). These findings suggest STEM-based microgreen seed paper learning effectively enhances science process skills and engagement, supporting SDG 4 (Quality Education) and SDG 12 (Responsible Consumption and Production).

Keywords :
STEM-based learning; Microgreen seed paper; Science process skills; Student – engagement; Sustainability education

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INTRODUCTION

Biology learning requires science process skills (observing, hypothesizing, identifying variables, analyzing data, and drawing conclusions) to build understanding through direct interaction with natural phenomena (Hartati *et al.*, 2022). Yet, teacher-centered instruction limits hands-on inquiry, leading to passive learning and hindering higher-order skills development aligned with SDG 4. Limited use of contextual, sustainable media also restricts understanding of responsible resource use, a key aspect of SDG 12. Few classroom strategies effectively develop SPS while integrating sustainability through concrete experiences (Simanjuntak, 2024).

The STEM approach, particularly project-based and experiential learning, has been widely acknowledged as beneficial in promoting science process skills, scientific reasoning, and higher-order thinking (Suryaningsih & Nisa, 2021; Darmaji *et al*., 2022; Subamia, 2023). STEM learning promotes active participation in observation, experimentation, and data analysis as fundamental components of scientific inquiry (Rosa & Susantini, 2020). In practice, however, the engineering and technology components are frequently limited by time, resources, and the availability of accessible learning media, leading to their utilization as supplemental tools rather than core parts of inquiry-based problem solving. While previous studies have shown that STEM-based e-modules, e-questions, and Project-Based Learning can improve creativity, problem-solving ability, critical thinking, and Higher Order Thinking Skills (Fernandu *et al*., 2022; Wulanningtyas & Ratnasari, 2022; Kartikasari, 2022) there remains a need for STEM learning approaches that are pedagogically effective, low-cost, and capable of meaningfully integrating science, technology, engineering, and mathematics within biological learning contexts.

Although STEM-based learning is well-studied, research on low-cost, eco-friendly, classroom-feasible media that develop both science process skills and sustainability is limited. Education for Sustainable Development research shows that organic and recycled materials can foster sustainability understanding (Havita *et al*., 2021), yet empirical studies using seed paper as a STEM medium are scarce. Microgreen seed paper combines biodegradable materials with rapid growth cycles, enabling continuous observation, data analysis, graphing, and evidence-based conclusions, supporting SPS development and SDG 12. Simple technologies like sensors further enhance engagement and skills (Wulanningtyas *et al*., 2023), but studies integrating inquiry, engineering design, and technology with seed paper remain limited, motivating this study.

This study is distinctive for using microgreen seed paper as an eco-friendly STEM learning medium and for its pedagogical design that positions the medium as central to scientific inquiry. Unlike previous studies relying on traditional labs, digital simulations, or instructional kits (Li *et al*., 2022; Wahono *et al*., 2020), students engage in the engineering design process, iteratively creating, testing, and refining the seed paper. Technology supports environmental data collection, growth visualization, and evidence-based reasoning. The short microgreen growth cycle allows repeated observation, data interpretation, and variable analysis, while recycled materials embed sustainability principles aligned with SDG 12, demonstrating that low-cost, environmentally responsible media can provide a coherent and meaningful STEM framework.

Recent studies show that STEM and STEAM approaches enhance students' science process skills through inquiry and discovery-based learning. Ecosystem modules improve observation and data analysis (Zulkarnain & Tanjung, 2023), while collaborative and guided STEM experiments promote SPS (Firdaus *et al*., 2020). STEAM worksheets and biology tools also support observation, data interpretation, and analytical thinking (Patresia *et al*., 2020; Nuraini *et al*., 2025; Suraida *et al*., 2025), and discovery-oriented STEM fosters investigative skills (Arifin *et al*., 2025). However, prior studies often relied on structured or short-term activities, limiting hands-on experimentation and sustainability integration. To address this, the current study introduces microgreen seed paper as a low-cost, tangible STEM medium for real-time biological observation and experiential inquiry, providing a more contextualized and unified learning framework.

Based on the preceding discussion, a significant research gap is recognized, specifically a lack of empirical classroom-based studies that use microgreen seed paper as a low-cost, eco-friendly STEM learning medium to build students' scientific process abilities within a restricted instructional timeframe. Therefore, this study intends to examine the efficacy of STEM-based learning via microgreen seed paper media, as evidenced by quantifiable enhancements in students' scientific process skills and learning responses. This study specifically seeks to analyze the enhancement of students' scientific process skills (observing, formulating hypotheses, identifying variables, analyzing data, and drawing conclusions) following their engagement in STEM-based learning facilitated by microgreen seed paper media, as well as to describe students' responses to the application of this pedagogical approach in biology education.

METHOD

This study employed a quantitative, one-group pretest-posttest design to examine the effect of STEM-based learning using microgreen seed paper on students' science process skills, allowing comparison of skill levels before and after the intervention without a control group (Creswell & Creswell, 2018). Conducted in class XI-9 at SMA Negeri 1 Krian, Sidoarjo (36 students) during the 2024/2025 even semester, the study focused on plant growth and development. The intervention engaged students in STEM-based activities, including learning early growth concepts, formulating research questions and hypotheses, preparing the planting medium, observing germination, measuring growth factors, and systematically collecting data.

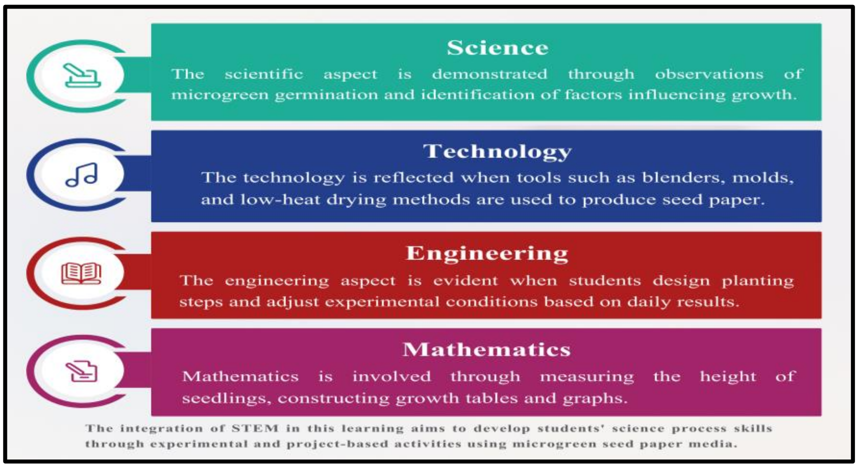

Figure 1. STEM Integration Scheme in the Learning Process

Figure 1. illustrates the STEM integration framework in the learning process. The science component included observing germination, identifying growth variables, and interpreting data; technology was used to collect environmental data using simple

measuring tools and digital sensors; engineering was realized by designing and fabricating microgreen seed paper; and mathematics supported quantitative measurement, data tabulation, and graphical analysis. In this context, the STEM-Based Microgreen Learning Media refers to a learning medium that integrates microgreen cultivation activities using seed paper with sensor-supported observation and data analysis, enabling students to directly engage in inquiry-based and interdisciplinary STEM practices. This integrated framework led learning activities that aligned with certain science process skills, with microgreen seed paper acting as the primary learning medium.

Figure 2. Production of Microgreen Seed Paper

The process of creating microgreen seed paper begins with combining recycled paper and tissue, as illustrated in Figure 2, which represents the engineering component of STEM education. Red and green amaranth seeds are evenly embedded throughout the paper to allow rapid germination and visible growth. This procedure not only demonstrates hands-on engineering design but also integrates sustainability concepts by reusing materials, aligning with SDG 12 (Responsible Consumption and Production). Once the paper has been prepared and the seeds embedded, it is transformed into a functional learning medium, which can be observed and monitored in real time. This transition to a usable biological observation tool can be seen in Figure 3.

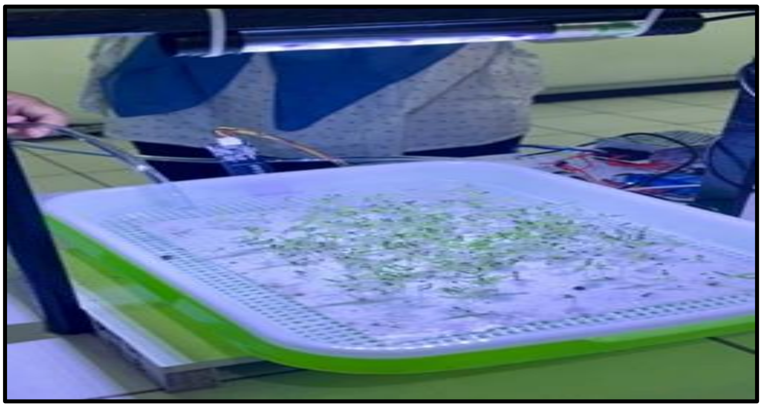

Figure 3. STEM-based Microgreen Seed Paper Media

Figure 3 displays the finished STEM-based microgreen seed paper medium, now equipped with humidity and light sensors, serving as the primary object for plant growth observation and data collection. The sensors provide quantitative feedback that supports evidence-based monitoring of the seeds' development, linking biological inquiry with technology in a STEM context. Using biodegradable and recycled materials further reinforces sustainability while providing students with a tangible, interactive learning experience consistent with SDG 4 (Quality Education).

Students actively engaged in observing phenomena, identifying variables, collecting and analyzing data, creating graphs, and drawing evidence-based conclusions through structured STEM-based project activities using microgreen seed paper. The learning design emphasized iterative skill development rather than solely assessing outcomes, including germination observation, quantitative plant height measurement, data recording, graphing growth trends, and guided reflection. Science process skills were measured using pretest and posttest essay instruments aligned with four indicators, while student perceptions were collected via a 1–4 Likert scale questionnaire on their STEM-based microgreen learning experience.

Science process skills were analyzed using students' pretest and posttest scores from essay-type questions covering four indicators: hypothesis formulation, variable identification, graph interpretation, and conclusion drawing.Student responses were evaluated using indicator-based scoring criteria to ensure that test items and targeted abilities were aligned.Individual scores were transformed into percentages by comparing their achieved scores to the highest possible score. A minimum mastery level of 75 was used, which corresponds to the usual minimum competency criterion typically used in Indonesian secondary education settings.Class-level achievement was calculated as the proportion of pupils who met or exceeded this benchmark in relation to the total number of participants. To provide an overall descriptive interpretation of learning outcomes, percentage results were classified using performance level categories adopted from Sugiyono (2019): 0-40% ("very poor"), 41-59% ("poor"), 60-69% ("fair"), 70-85% ("good"), and 86-100% ("very good"). This category was used to explain the overall pattern of students' science process skill attainment after the intervention, rather than to diagnose individual skill mastery in detail.

This methodology aligns with research evaluating the advancement of students' science competencies by systematic analysis of conceptual and procedural performance, as articulated by Sinta & Agustina (2024). The application of structured rubrics is pertinent to prior studies on assessing science process abilities in applied science education, as noted by Hanum *et al*. (2024). Prior to performing the difference test, the data underwent normality assessment via the Shapiro–Wilk test and homogeneity evaluation by the Levene test. According to Wardani *et al*. (2025), these two tests are essential prerequisites prior to the application of parametric tests in educational research. Should both assumptions be satisfied, the analysis is conducted utilizing a paired sample t-test. If any of the assumptions for parametric testing are violated, a nonparametric alternative is applied. In this study, the Wilcoxon signed-rank test was used as a robust alternative to assess differences between pretest and posttest scores, as it does not require the assumptions of normality or homogeneity of variance. This approach ensures that the statistical analysis remains valid and reliable even when the data distribution deviates from parametric requirements.

The normalized gain (N-gain) index was employed to evaluate the effectiveness of the STEM-based learning intervention using microgreen seed paper media in enhancing students' science process skills. N-gain provides a standardized measure of how much students' learning improved relative to the maximum possible improvement. It is calculated by taking the difference between each student's posttest and pretest scores and dividing it by the difference between the maximum possible score and the pretest score, following the formula proposed by Hake (1998). This approach focuses on quantifying the extent of learning improvement achieved through the intervention rather than determining causal relationships. N-gain values were categorized into three levels—high, medium, and low—based on established criteria, as shown in Table 1. High N-gain values indicate significant improvement in students' science process abilities, while medium and low values reflect moderate and minimal gains, respectively. Using this method, the study could objectively assess the impact of STEM-based microgreen seed paper on students' abilities to formulate hypotheses, identify variables, interpret data, and draw conclusions.

Table 1. Criteria for Interpreting N-gain Values (Hake, 1998)

No	Scale	Category
1	0,70 < N-gain	High
2	0,30 ≤ N-gain ≤ 0,70	Medium
3	N-gain < 0,30	Low

The responses of students to the installation of microgreen seed paper-assisted STEM learning were examined to measure the level of acceptance of the learning approach. Data were gathered using a Guttman scale questionnaire with dichotomous responses ("Yes" = 1; "No" = 0), which was chosen to provide a clear and direct indicator of students' impressions of their learning experience. The overall response score was calculated as a percentage by comparing the acquired score to the maximum possible score.The percentages were evaluated using response categories developed from Sugiyono (2019), which were: 0-40% ("very poor"), 41-59% ("poor"), 60-69% ("fair"), 70-85% ("good"), and 86-100% ("very good"). This classification approach is often used in educational research focused on the evaluation of learning media acceptability, and it was chosen to provide a descriptive summary of students' reactions, in line with prior learning media development studies (Tampubolon & Sipahutar, 2024).

RESULT AND DISCUSSION

The findings demonstrate that implementing STEM-based learning with microgreen seed paper media significantly improved students' science process skills. Overall, students' performance improved significantly between the pretest and the posttest, demonstrating that the learning intervention effectively aided the development of core scientific competencies. Students' science process skills were assessed using four indicators: developing hypotheses, identifying variables, interpreting graphs, and drawing conclusions. Figure 4 depicts the average pretest, posttest, and N-gain scores for each indicator, demonstrating consistent progress in all measured parts of science process skills following the STEM learning experiences.

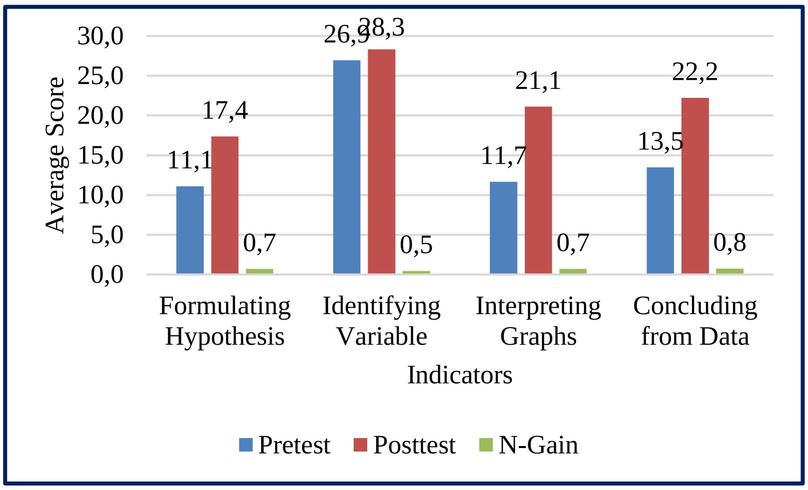

Figure 4. Average Pretest, Posttest, and N-gain Scores of Students for Each Question Indicator According to Science Process Skills Indicators

Figure 4 shows the average pretest, posttest, and N-gain scores for four science process skill indicators: Formulating Hypotheses, Identifying Variables, Interpreting Graphs, and Drawing Conclusions from Data. Overall, posttest scores improved across all indicators. The highest gain was observed in "Drawing Conclusions from Data" (N-gain = 0.8), followed by "Formulating Hypotheses" and "Interpreting Graphs" (N-gain = 0.7), while "Identifying Variables" showed the lowest improvement (N-gain = 0.5). These results indicate that the intervention was particularly effective in enhancing students' ability to draw conclusions, but less so in variable identification. Detailed pretest and posttest scores are presented in Table 2.

Table 2. Students' Pretest and Posttest Scores

Description	Pretest Score	Posttest Score	N-Gain	Category
Average	63.19	89.03	0.71	High
Percentage of Achievement of Science Process Skills	92%			
Interpretation of Achievement of Science Process Skills	Very Good			

The calculated N-gain values confirm the intervention's effectiveness. As indicated in Table 2, the average N-gain of 0.71 is in the high range, and the overall achievement percentage of 92% is considered very good. These findings show that the majority of students successfully attained the anticipated level of science process abilities after engaging in STEM-based learning using microgreen seed paper media. Figure 4. illustrates that the pretest and posttest findings indicate an enhancement in students' science process skills across all metrics following the adoption of STEM education facilitated by microgreen seed paper media. The mean student scores rose from 63.19 on the pretest to 89.03 on the posttest, yielding an N-gain value of 0.71, categorized as high (Table 2). This rise indicates that STEM education, when integrated with contextual media, can promote significant learning experiences grounded in real-world activities. The findings align with the research conducted by Zulkarnain & Tanjung (2023), which indicated that contextual module-based STEM learning significantly enhances students' science process skills. This is further supported by Firdaus *et al*. (2020), who asserted that the incorporation of experimental activities in STEM education positively influences the advancement of students' science skills.

The improvement in students' science process skills observed in this study is strongly aligned with international findings in STEM education research, particularly those emphasizing the role of inquiry-based and integrated learning environments. Systematic reviews of high-impact empirical studies highlight that STEM instruction which actively involves learners in inquiry, experimentation, and analytical reasoning consistently produces positive outcomes in students' scientific competencies (Li *et al*., 2020, 2022). These studies indicate that science process skills develop most effectively when students are provided with opportunities to engage in authentic scientific practices rather than relying on passive or teacher-centered instruction. Consequently, STEM learning environments that emphasize investigation, data interpretation, and evidence-based reasoning are widely recognized as essential for fostering higher-order scientific skills across different educational contexts.

From a theoretical standpoint, integrated STEM education emphasizes that meaningful learning occurs when students actively connect scientific concepts with real-world applications through inquiry, problem solving, and data-driven decision-making processes (English, 2016; Kelley & Knowles, 2016). The use of microgreen seed paper in STEM-based learning in this work operationalizes these ideas not only via scientific observation, but also through the incorporation of engineering and technological processes. The engineering component is demonstrated in students' involvement in the design and preparation of seed paper as a functional growing medium, which required careful consideration of material qualities, seed dispersal, and environmental factors. Simultaneously, The integration of humidity and light sensors adds a technological dimension to the learning medium, enhancing the accuracy of data collection and enabling evidence-based analysis of plant growth patterns. This feature allows students to monitor environmental conditions in real time and supports precise interpretation of growth trends, bridging hands-on experimentation with technology-driven observation in STEM-based biology education.

Theoretically, this combination strengthens the inquiry cycle by connecting experimental observation with iterative decision-making, which is a critical feature of realistic STEM learning settings. Hands-on and inquiry-oriented STEM activities, consistent with international findings, have been demonstrated to improve not only conceptual knowledge but also students' cognitive engagement, epistemic curiosity, and long-term enthusiasm in scientific inquiry (Stuppan *et al*., 2025). The contextual nature of microgreen cultivation connects abstract biological concepts to observable phenomena, facilitating the development of science process skills across diverse indicators, as reported in STEM learning contexts at various educational levels (Ku *et al*., 2022; Larkin & Lowrie, 2023). Furthermore, when viewed through the lens of Education for Sustainable Development, using recycled paper as a growth medium introduces students to principles of responsible resource use and environmentally conscious practices, aligning STEM inquiry with broader educational goals related to SDG 12.

Figure 5. Documentation of STEM-Based Learning Activities Using Microgreen Seed Paper

Figure 5 illustrates the implementation of STEM-based learning using microgreen seed paper, showing students actively engaged in hands-on tasks such as observing plant growth, handling the seed paper, recording data, and participating in small-group discussions. This visual evidence complements the quantitative results by demonstrating active, inquiry-based learning, student engagement, teamwork, and direct interaction with biological phenomena. The photographs also reflect the integration of STEM components: science through plant observation and data collection, technology via simple measurement tools, engineering through seed paper creation, and mathematics in measuring and organizing data. While Figure 5 focuses on engagement and procedural implementation rather than full interdisciplinary reasoning, it reinforces the authenticity and student-centered nature of the learning activities documented in the study.

Normality testing was used to select the most appropriate inferential statistical approach. The Shapiro-Wilk test, suited for small to intermediate sample sizes (n = 36), revealed that both pretest and posttest scores deviated from a normal distribution ($p < 0.05$). The results show that the assumption of normalcy was not met. Although Levene's test revealed that the variances of pretest and posttest scores were homogeneous (Sig. = 0.132 > 0.05), variance homogeneity is not required for non-parametric analysis. As a result, a Wilcoxon signed-rank test was used to compare differences in students' science process skills before and after the intervention, as shown in Table 3 and Table 4.

Table 3. Results of the Wilcoxon Signed Ranks Test for Student Pretest-Posttest Scores

Wilcoxon Signed Ranks Test				
		N	Mean Rank	Sum of Ranks
Postest - Pretest	Negative Ranks	0[a]	.00	.00
	Positive Ranks	36[b]	18.50	666.00
	Ties	0[c]		
	Total	36		

a. Postest < Pretest; b. Postest > Pretest; c. Postest = Pretest

Table 3. presents the results of the Wilcoxon signed-rank test comparing students' pretest and posttest scores. The analysis shows that all 36 students demonstrated positive

ranks, meaning that every student achieved a higher score on the posttest compared to the pretest. There were no negative ranks, indicating that no student's posttest score was lower than their pretest score, and no ties, meaning no student had identical pretest and posttest scores. The mean rank of positive differences was 18.50, with a total sum of ranks of 666.00. These results indicate a consistent and statistically significant improvement in students' science process skills following the STEM-based learning intervention using microgreen seed paper. The findings support the effectiveness of the intervention and align with the outcomes reported by the N-gain analysis.

Table 4. Results of the Wilcoxon Statistical Test of Student Pretest-Posttest Scores

Test Statistics[a]	
	Postest - Pretest
Z	-5.248[b]
Asymp. Sig. (2-tailed)	.000

a. Wilcoxon Signed Ranks Test; b. Based on negative ranks.

The Wilcoxon signed-rank test ($Z = -5.248$, $p < 0.001$) revealed a statistically significant improvement in students' science process skills after participating in STEM-based learning using microgreen seed paper media. All 36 paired observations showed positive ranks, with no negative ranks or ties, indicating consistent gains across the sample. These results provide empirical evidence that the intervention enhanced abilities such as formulating hypotheses, identifying variables, interpreting data, and drawing conclusions, supporting the effectiveness of activity-based, hands-on instructional approaches reported in prior studies (Novallyan & Nehru, 2025; Nofriadi & Kurnia, 2024; Nuraini *et al*., 2025; Tampubolon & Sipahutar, 2024). While the one-group pretest-posttest design demonstrates learning progress, it does not establish causal effects, yet it aligns with previous findings that contextual, Inquiry-based media has succeeded in developing scientific abilities or skills.

A more extensive review of science process skill indicators showed that the variable identification indicator had a lower N-gain than the other indicators. This finding indicates that, while students made significant progress overall, identifying and distinguishing experimental variables remains a difficult area of scientific investigation. Previous research has found that variable determination necessitates higher-level analytical reasoning and explicit scaffolding since it includes comprehending causal links within experimental designs (Angelia *et al*., 2022). In the context of this study, the microgreen seed paper activities focused mostly on observation, data collecting, and result interpretation, which may have resulted in less structured chances for students to manipulate and control factors.Nonetheless, the observed improvement suggests that hands-on experimental engagement with microgreen media continues to positively contribute to students' conceptual knowledge of variables, in line with findings from experiment-based biology learning environments (Patresia *et al*., 2020). This finding emphasizes the need for future STEM education designs to include more explicit engineering-oriented assignments that require students to actively organize, change, and evaluate experimental variables.

The relatively lower improvement observed in the variable determination indicator aligns with international research identifying variable identification and control as complex cognitive skills that require explicit instructional support and repeated practice. Studies conducted in inquiry-based STEM classrooms demonstrate that students often experience difficulty distinguishing independent, dependent, and controlled variables, even when they show improvement in other aspects of experimental performance (Heppt *et al*., 2023; Ješkov & Luk, 2022). This challenge arises because variable identification demands higher-level analytical thinking, including understanding causal relationships and anticipating the effects of manipulating specific factors within an experimental design. As a result, gains in this indicator tend to progress more gradually compared to skills such as observation or data recording.

Consistent trends have been described in biology and laboratory-based STEM learning environments, where students' understanding of experimental variables gradually increases through persistent exposure to guided inquiry activities (Chengere *et al*., 2025; Jehadan *et al*., 2020). The current study's relatively low increase in variable determination could be attributed to the complexity of the integrated learning environment, in which biological growth processes were regulated simultaneously by several interacting elements contained inside the microgreen seed paper system. The combination of biological observation, basic technological support, and tailored planting media may produce overlapping variables that necessitate higher-level analytical distinction. Nonetheless, the overall gain in science process skills implies that frequent and structured inquiry experiences in such interdisciplinary contexts can enhance long-term skill development (Dosymov *et al*., 2025; Wu *et al*., 2021). These findings show that, while integrated STEM learning environments may initially test students' ability to isolate variables, they also provide authentic conditions that mimic real scientific investigations, providing meaningful opportunities for long-term development of advanced science process skills.

There were significant improvements in graph interpretation and conclusion formulation indicators. Throughout the learning process, students collected microgreen growth data and converted it into graphical representations, which required them to recognize patterns, analyze growth trends, and generate evidence-based judgments. The availability of recurrent, real-time growth data, aided by cheap technical instruments, enabled students to delve further into data analysis methods than in traditional short-term trials. These findings are congruent with those of Wahyuningtyas *et al*. (2025) and Andini & Mahardika (2024), who argue that structured data processing and visual representation improve analytical thinking. Furthermore, in the context of microgreen-based STEM learning, conclusion formulation went beyond biological outcomes to address resource efficiency and sustainable cultivation approaches.This agrees with Arifin *et al*. (2025), who found that STEM learning based on observation and data analysis can successfully improve science process abilities. Thus, combining data-driven inquiry with sustainable learning media not only improved students' analytical skills, but also promoted a more thorough scientific reasoning process applicable to real-world and sustainability situations.

In addition to the reported improvement in students' science process abilities, the learning activities seen in this study have the potential to influence the development of higher-order thinking and self-directed learning. Although these constructs were not directly measured, students' sustained participation in observation, systematic data recording, group debate, and conclusion formulation exemplifies fundamental aspects of collaborative inquiry learning. According to Irwanto (2023), research-oriented collaborative inquiry environments promote learners to engage in reflective and metacognitive processes as well as procedural scientific tasks.The current study suggests that microgreen seed paper-assisted STEM learning can foster higher-order cognitive engagement and learner autonomy, particularly through opportunities for reflection, peer interaction, and iterative decision-making during experimental activities.

Furthermore, the outcomes of this study are congruent with broader STEM education research in Asian contexts, which highlights the value of contextualized and activity-based learning methods. Wahono *et al*. (2020) found that STEM implementation based on real-world contexts improves students' scientific competencies, whereas Perdana & Sujadi (2017) found that embedding science process skills within hands-on instructional media can increase students' motivation and cognitive engagement. In comparison to past investigations, the current study makes a contribution by demonstrating that microgreen seed paper, which serves as both a biological medium and a learning setting focused on sustainability, may effectively enhance the development of science process skills. Rather than simply confirming previous findings, this study suggests that incorporating environmentally relevant media into STEM learning may improve the contextual quality of students' learning experiences, while also acknowledging the need for additional research to empirically examine its impact on higher-order thinking and self-directed learning outcomes.

Long-term educational research has shown that inquiry-based STEM learning is linked to the development of self-regulated learning and students' future inclination toward STEM areas. Wyk *et al*. (2025) and Lewalter *et al*. (2025) found that inquiry-based STEM environments that include students in developing, monitoring, and evaluating learning activities can increase learner autonomy and interest in future scientific careers. The current study, however, did not directly examine such long-term consequences. As a result, these findings should be considered as prospective pedagogical implications, implying that microgreen seed paper-assisted STEM learning may produce learning environments conducive to self-regulated learning and future STEM engagement, rather than empirically validated impacts. This distinction is critical for ensuring that the study's methodological scope is consistent with its conceptual claims.

In addition to quantitative increases in science process abilities, the effectiveness of microgreen seed paper-assisted STEM learning was evaluated using students' responses to the learning process. A 15-item questionnaire was administered at the end of the learning intervention, and students' perceptions were measured using the Guttman scale to capture unequivocal affirmative or negative responses to essential features of the learning experience. This measure was created to assess students' acceptance, engagement, and perceived usefulness of STEM activities, which will supplement the objective learning goals. While post-intervention comments may be influenced by response bias, the statistics confirm students' positive perceptions of the learning model. Table 5 displays the complete results of students' replies, which are addressed as extra indicators that contextualize the observed advances in science process abilities rather than standalone assessments of learning efficacy.

Table 5. Percentage Results of Student Response Questionnaire

No	Statement	Response Rate (%)
1	The use of microgreen seed paper is new and interesting for students.	97
2	STEM learning with microgreen seed paper media makes learning activities more enjoyable.	100
3	Learning activities are assessed in accordance with growth and development materials.	97
4	Students are more motivated to learn because they use microgreen seed paper.	97
5	The microgreen practicum helps students understand plant growth better.	100
6	Students feel more skilled at analyzing microgreen observation data.	97
7	Learning helps students develop science process skills, such as connecting data and drawing conclusions.	100
8	The use of tools or sensors helps students understand technology and biology.	97
9	Project activities encourage more active and collaborative group work.	97
10	Students feel well guided when carrying out STEM project activities using microgreen seed paper.	100
11	Students became better able to answer questions that required scientific process skills after participating in the learning activities.	97
12	The learning process makes students more concerned about environmental issues such as paper recycling and sustainability.	94
13	Students feel more confident when presenting the results of their microgreen projects.	83
14	The microgreen project helps students connect biological concepts to everyday life.	100
15	In general, students rated STEM learning using microgreen seed paper as effective and beneficial.	100
	Average Percentage Score	97

The findings from the student response questionnaire in “Table 5” indicate that microgreen seed paper-assisted STEM learning garnered an exceptionally favorable reaction, achieving an average percentage of 97%. The majority of students indicated that the medium utilized was engaging, fun, and enhanced their comprehension of the subject regarding plant growth and development. The strong affirmative answer suggests that environment-based learning media can enhance student interest and participation in the educational process. The findings align with the research conducted by Adelia & Wandini (2023) and Zendrato *et al*. (2024), which asserts that context-based learning media enhances learning motivation by offering experiences relevant to students' daily life.

The novelty of the learning media appeared to play an early influence in influencing students' favorable reactions to the learning activities. The introduction of microgreen seed paper, which was unknown to students and had not previously been used in biology education, helped to capture their attention and increase their willingness to participate in the early stages of the exercise. However, this positive response should not be construed as proof of long-term educational impact. Because student responses were measured on a binary Guttman scale, the statistics mostly represent students' surface-level acceptance and interest, rather than nuanced perceptions of multidisciplinary STEM integration or sustainability-oriented instruction. In this setting, novelty serves as a supportive condition for engagement rather than a predictor of learning effectiveness. This interpretation is consistent with Suraida *et al*. (2025) and Hanum *et al*. (2024), who emphasize that innovative and activity-based biology media can increase student interest and involvement, but that such engagement must be accompanied by structured inquiry and instructional depth in order to contribute meaningfully to science process skill development.

The students' positive response was also apparent in the relevance of the learning activities to the subject matter being examined. The majority of students believed that the activities of planting and monitoring the growth of microgreens aligned with the content on plant growth and development. This indicates that the integration of the material's content with the learning activities was seamless. The findings align with the research conducted by Zulkarnain & Tanjung (2023), which indicated that STEM education tailored to the material's characteristics enhances students' conceptual comprehension and engagement. This is further supported by Firdaus *et al*. (2020), who asserted that the alignment of activities with the material is crucial for the efficacy of STEM-based learning.

From the aspect of learning motivation, most students stated that the use of microgreen seed paper media makes them more motivated to participate in learning. Activities such as planting, observing, and recording plant growth provide an active and non-monotonous learning experience. This shows that activity-based learning can encourage students' intrinsic motivation. These findings are in line with the results of research by Nofriadi & Kurnia (2024), which states that activity-based science learning can increase student motivation and participation, and is reinforced by Lestari *et al*. (2023), who asserts that STEM learning can create a more challenging and interesting learning atmosphere for students.

Students reported that microgreen practicum activities enhanced their understanding of biological concepts by linking theory to observable growth processes, consistent with Nuraini *et al*. (2025) and Patresia *et al*. (2020). While STEM and sustainability were embedded, responses mainly reflected conceptual comprehension rather than broader transdisciplinary or value-oriented learning. Collaborative aspects were also positively perceived, with students engaging in group tasks and discussions, supporting social interaction during STEM-based activities, as noted by Andriani & Trisnowati (2025) and Novallyan & Nehru (2025); however, these data reflect short-term perceived engagement rather than long-term skill development. Although overall responses were positive, students' confidence in presenting project findings was lower (83%), indicating that scientific communication skills were not fully developed, aligning with Syafutri & Soeharto (2019) and Rukmana *et al*. (2024) on the need for explicit instructional support. STEM learning with microgreen seed paper was well-received, promoting engagement, teamwork, and hands-on experiences, while fostering awareness of sustainability, consistent with Suraida *et al*. (2025) and Zulkarnain & Tanjung (2023).

Beyond improvements in science process skills, this study contributes to the broader international discourse on sustainability-oriented STEM education by demonstrating the pedagogical feasibility of integrating environmental contexts into inquiry-based biology learning. Recent studies emphasize the necessity of incorporating sustainability concepts and authentic real-world contexts into STEM training to help learners prepare to face global challenges (Vermehren, 2025; Wang *et al*., 2025). In this study, the use of microgreen seed paper places scientific inquiry in an environmentally relevant setting, allowing students to interact with biological concepts through activities that are intimately related to sustainable practices. Although environmental attitudes and values were not directly examined, the learning design demonstrates how sustainability-oriented resources can be effectively integrated into STEM instruction to supplement the development of scientific skills.

In contrast to many STEM learning approaches that rely on digital simulations, laboratory-intensive equipment, or advanced technological infrastructure (Megawati, 2024; Yesnazar *et al*., 2024), the results of this study demonstrate that eco-friendly and low-cost instructional media, such as microgreen seed paper, effectively support inquiry-based learning and the development of science process skills. The use of recycled paper as a planting medium offers a practical and sustainable STEM learning approach that can be implemented in resource-limited educational settings without compromising learning quality. These findings contribute to SDG 4 (Quality Education) through skill-oriented science learning and support SDG 12 (Responsible Consumption and Production) by promoting environmentally responsible learning media.

CONCLUSION

This study found that STEM-based learning using microgreen seed paper media leads to a significant improvement in senior high school students' science process skills in plant growth and development issues. Integrating hands-on biological inquiry with contextual learning media can effectively develop key science process skills such as hypothesis formulation, variable identification, data interpretation, and conclusion drawing, as evidenced by a high N-gain value (0.71) and a significant Wilcoxon test result ($p < 0.05$). The students' overwhelmingly positive replies suggest that the learning activities were seen as interesting and relevant. Despite the constraints of a single-group research design, these findings provide empirical support for microgreen seed paper's educational potential as a context-rich medium for STEM-oriented biology education.

Beyond its classroom performance, this study provides a proof of concept for the use of eco-friendly and low-cost learning media in STEM education with a focus on sustainability. The incorporation of plant culture operations using recycled seed paper demonstrates how scientific research can be placed in real-world and environmentally relevant contexts without relying on resource-intensive laboratory infrastructure. Nonetheless, this study is constrained by its scope, research design, and dependence on short-term cognition and reaction data. Future study should use comparative or mixed-method designs, investigate the specific contributions of technology and engineering components within the STEM framework, and directly measure outcomes such as scientific communication skills and environmental awareness. Such studies are required to more fully validate the role of microgreen seed paper-assisted STEM learning as an inclusive and sustainable approach to science education.

REFERENCES

Adelia, M., & Wandini, R. R. (2023). Media interaktif berbasis kearifan lokal tri hita karana berbantuan articulate storyline untuk meningkatkan hasil belajar PPKn siswa. *Jurnal Ilmiah Pendidikan Dan Pembelajaran*, *7*(3), 528–536. https://doi.org/10.23887/jipp.v7i3.61599

Andini, A. D., & Mahardika, I. K. (2024). Creative problem solving accompanied by wordwall as an assessment media : does it have an impact on students ' higher level physics thinking abilities ? *International Journal of Education and Teaching Zone*, *3*(2), 152–160. https://doi.org/10.57092/ijetz.v3i2.224

Andriani, A., & Trisnowati, E. (2025). Integrating problem-based learning and the teaching at the right level approach to improve students' collaboration skills. *International Journal of Education and Teaching Zone*, *4*(3), 406–422. https://doi.org/10.57092/ijetz.v4i3.515

Angelia, Y., Supeno, & Suparti. (2022). Keterampilan proses sains siswa sekolah dasar dalam pembelajaran ipa menggunakan model pembelajaran inkuiri. *Jurnal BasicEdu*, *6*(5), 8296–8303. https://doi.org/10.31004/basicedu.v6i5.3692

Arifin, U. K., Supriyatin, S., & Isfaeni, H. (2025). Improving student's marine literacy and science process skills through STEM-based discovery learning. *Research and Development in Education (RaDEn)*, *5*(1), 463–474. https://doi.org/10.22219/raden.v5i1.39726

Chengere, A. M., Bono, B. D., Zinabu, S. A., & Jilo, K. W. (2025). Enhancing secondary school students' science process skills through guided inquiry-based laboratory activities in biology. *PLOS ONE*, 1–18. https://doi.org/10.1371/journal.pone.0320692

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications.

Darmaji, Kurniawan, A., & Rini, E. F. S. (2022). Science processing skill and critical thinking: reviewed based on the gender. *Jurnal Pendidikan Indonesia (JPI) Undhiksa*, *11*(1), 133–141. https://doi.org/10.23887/jpi-undiksha.v11i1.35116

Dosymov, Y., Ergobek, E., Ramankulov, S., Ualikhan, A., Usembayeva, I., & Kurbanbekov, B. (2025). A new approach to development of students' research abilities in STEM education. *Emerging Science Journal*, *9*(2), 741–763. https://doi.org/10.28991/ESJ-2025-09-02-013

English, L. D. (2016). STEM education K-12: perspectives on integration. *International Journal of STEM Education*, *3*(1), 1–8. https://doi.org/10.1186/s40594-016-0036-1

Fernandu, D. E., Abdurrahman, & Lengkana, D. (2022). Design and validation of STEM integrated e-modules on PjBL to improve problem solving skills. *Jurnal Pendidikan MIPA*, *23*(2), 754–765. http://dx.doi.org/10.23960/jpmipa/v23i2.pp754-765

Firdaus, F., Subchan, W., & Narulita, E. (2020). Developing STEM-based TGT learning model to improve students ' process skills. *Jurnal Pendidikan Biologi Indonesia (JPBI)*, *6*(3), 413–422. https://doi.org/10.22219/jpbi.v6i3.12249

Hake, R. R. (1998). Interactive-engagement versus traditional methods : A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, *66*(1), 64–74. https://doi.org/10.1119/1.18809

Hanum, W. N., Nuha, U., & Ridlo, Z. R. (2024). Development of scaffolding-based science e-modules to improve junior high school students ' scientific reasoning. *ORBITA: Jurnal Pendidikan Dan Ilmu Fisika*, *10*(2), 185–193. https://doi.org/10.31764/orbita.v10i2.26773

Hartati, H., Azmin, N., Nasir, M., & Andang, A. (2022). Keterampilan proses sains siswa melalui model pembelajaran problem based learning (PBL) pada materi biologi. *Jurnal Ilmiah Ilmu Pendidikan (JIIP)*, *5*(12), 5795–5799. https://doi.org/10.54371/jiip.v5i12.1190

Havita, V. nurhikmah, Hamidah, I., & Sriyati, S. (2021). Education sustainable development-integrated organic waste management to improve students' sustainability literacy. *Jurnal Pendidikan MIPA*, *22*(2), 262–269. http://dx.doi.org/10.23960/jpmipa/v22i2.pp262-269

Heppt, B., Henschel, S., Hardy, I., & Gabler, K. (2023). Instructional support in inquiry-based elementary school science classes : how does it relate to students' science content knowledge and academic language proficiency?. *European Journal of Psychology of Education*, *38*(4), 1377–1401. https://doi.org/10.1007/s10212-022-00653-6

Irwanto, I. (2023). Improving preservice chemistry teachers' critical thinking and science process skills using research-oriented collaborative inquiry learning. *Journal of Technology and Science Education*, *13*(1), 23–35. https://doi.org/10.3926/jotse.1796

Jehadan, H., Nur, M., & Supardi, Z. A. I. (2020). The development of physics guided inquiry learning package to facilitate the science process skills of senior high school. *International Journal for Educational and Vocational Studies*, *2*(10), 847–852. https://doi.org/10.29103/ijevs.v2i10.3307

Ješkov, Z., & Luk, S. (2022). Active learning in STEM education with regard to the development of inquiry skills. *Education Sciences*, *12*(10), 666. https://doi.org/10.3390/educsci12100666

Kartikasari, S. (2022). STEM-project based learning with learning guides to improve higher order thinking skills. *Jurnal Pendidikan MIPA*, *23*(3), 1214–1223. http://dx.doi.org/10.23960/jpmipa/v23i3.pp1214-1223

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*, 1–11. https://doi.org/10.1186/s40594-016-0046-z

Ku, C. J., Hsu, Y. S., Chang, M. C., & Lin, K. Y. (2022). A model for examining middle school students' STEM integration behavior in a national technology competition. *International Journal of STEM Education*, *9*(3), 1–13. https://doi.org/10.1186/s40594-021-00321-z

Larkin, K., & Lowrie, T. (2023). Teaching pproaches for STEM integration in pre - and primary school: a systematic qualitative literature review. *International Journal of Science and Mathematics Education*, *21*, 11–39. https://doi.org/10.1007/s10763-023-10362-1

Lestari, D. A., Suwarma, I. R., & Suhendi, E. (2023). Development of STEM-based physics e-module with self- regulated learning to train students' creative thinking skills. *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, *9*(2), 197–206. https://doi.org/10.21009/1.09202

Lewalter, D., Neubauer, K., & Moser, S. (2025). Self-regulated STEM learning in museums — the role of learner characteristics and visit - related activities in school. *International Journal of STEM Education*, *12*, 56. https://doi.org/10.1186/s40594-025-00577-9

Li, Y., Wang, K., Xiao, Y., & Froyd, J. E. (2020). Research and trends in STEM education: a systematic review of journal publications. *International Journal of STEM Education*, *7*, 1–16. https://doi.org/10.1186/s40594-020-00207-6

Li, Y., Xiao, Y., Wang, K., Zhang, N., Pang, Y., Wang, R., Qi, C., Yuan, Z., Xu, J., Nite, S. B., & Star, J. R. (2022). A systematic review of high impact empirical studies in STEM education. *International Journal of STEM Education*, *9*(1), 1–18. https://doi.org/10.1186/s40594-022-00389-1

Megawati, R. (2024). Integration of project-based learning in science, technology, engineering, and mathematics to improve students' biology practical skills in higher education: A systematic review. *Open Education Studies*, *6*(1), 51–65. https://doi.org/10.1515/edu-2024-0049

Nofriadi, N., & Kurnia, Y. (2024). Problem-based learning through outdoor learning or conventional learning : How is it different for science subjects?. *International Journal of Education and Teaching Zone*, *3*(3), 246–259. https://doi.org/10.57092/ijetz.v3i3.315

Novallyan, D., & Nehru. (2025). Optimization of teaching profession courses through project methods : Impact on biology education students. *International Journal of Education and Teaching Zone*, *4*(2), 126–143. https://doi.org/10.57092/ijetz.v4i2.431

Nuraini, A. M., Susantini, E., Indah, N. K., & Ishak, N. A. (2025). Validating a pteridophyta atlas integrated with local wisdom for enhancing science process skills. *International Journal of Education and Teaching Zone*, *4*(2), 144–162. https://doi.org/10.57092/ijetz.v4i2.418

Patresia, I., Silitonga, M., & Ginting, A. (2020). Developing biology students' worksheet based on STEAM to empower science process skills. *Jurnal Pendidikan Biologi Indonesia (JPBI)*, *6*(1), 147–156. https://doi.org/10.22219/jpbi.v6i1.10225

Perdana, F. A., & Sujadi, I. (2017). Development of e-module combining science process skills and dynamics motion material to increasing critical thinking skills and improve student learning motivation senior high school. *International Journal of Science and Applied Science: Conference Series*, *1*(1), 45–54.

https://doi.org/10.20961/ijsascs.v1i1.5112

Rosa, W. F., & Susantini, E. (2020). Validitas pengembangan LKS berbasis CTL pada materi ekosistem untuk melatihkan keterampilan proses sains siswa kelas X SMA. *BioEdu: Berkala Ilmiah Pendidikan Biologi*, *9*(3), 397–405. https://doi.org/10.26740/bioedu.v9n3.p397-405

Rukmana, R., Susantini, E., & Borhan, M. T. (2024). Development of PjBL teaching module based on Jombang's local wisdom for training science entrepreneurship skills. *Edubiotik: Jurnal Pendidikan, Biologi Dan Terapan*, *9*(02), 154–168. https://doi.org/10.33503/ebio.v9i02.243

Simanjuntak, Y. I. wati. (2024). STEM integrated problem based learning: Procedures and impacts on critical thinking. *Jurnal Pendidikan MIPA*, *25*(2), 686–700. https://doi.org/10.23960/jpmipa/v25i2.pp686-700

Sinta, A. D., & Agustina, P. (2024). Science process skills and biology learning outcomes of high school students through the application of the guided inquiry learning model. *Edubiotik: Jurnal Pendidikan, Biologi Dan Terapan*, *9*(01), 45–53. https://doi.org/10.33503/ebio.v9i01.4021

Stuppan, S., Rehm, M., Schijndel, T. J. P. Van, & Wilhelm, M. (2025). Do STEM education problem - solving tasks trigger learners' epistemic curiosity ? And why we should be astonished. *International Journal of STEM Education*, *12*, 1–14. https://doi.org/10.1186/s40594-025-00557-z

Subamia, I. D. P. (2023). Keterampilan proses sains dan hasil belajar siswa pada pembelajaran menggunakan pendekatan starter experiment. *Jurnal Pendidikan Dan Pengajaran (JPP) Undiksha*, *45*(1), 2023. https://doi.org/10.23887/jppundiksha.v45i1.1780

Sugiyono. (2019). *Metode Penelitian Pendidikan: Pendekatan Kuantitatif, Kualitatif. dan R&D*. Alfabeta.

Suraida, Saputra, J., Salahuddin, Syefrinando, B., & Susanti, T. (2025). E-encyclopedia for biology education : Design, development, and evaluation of an innovative learning resource. *International Journal of Education and Teaching Zone*, *4*(2), 223–242. https://doi.org/10.57092/ijetz.v4i2.442

Suryaningsih, S., & Nisa, F. A. (2021). Kontribusi steam project based learning dalam mengukur keterampilan proses sains dan berpikir kreatif siswa. *Jurnal Pendidikan Indonesia*, *2*(6), 1097–1111. https://doi.org/10.59141/japendi.v2i06.198

Syafutri, R., & Soeharto. (2019). Movable book development to improve students' science process skills. *Jurnal Pendidikan Indonesia (JPI Undiksha)*, *8*(1), 141–150. https://doi.org/10.23887/jpi-undiksha.v8i1.15640

Tampubolon, M. L. V., & Sipahutar, H. (2024). Development of project-based modules to improve learning outcomes, critical thinking and problem-solving skills. *Jurnal Pendidikan Biologi Indonesia (JPBI)*, *10*(2), 531–541. https://doi.org/10.22219/jpbi.v10i2.32958

Vermehren, J. A. V. (2025). How STEM students think : An AI-powered systematic review of thinking skills in STEM higher education. *Discover Education*, *4*, 1–25. https://doi.org/10.1007/s44217-025-00936-2

Wahono, B., Lin, P., & Chang, C. (2020). Evidence of STEM enactment effectiveness in Asian student learning outcomes. *International Journal of STEM Education*, *7*, 1–18. https://doi.org/10.1186/s40594-020-00236-1

Wahyuningtyas, P. A., Wahyuni, S., & Rusdianto. (2025). Pengembangan modul IPA berbasis STEM dalam meningkatkan keterampilan proses sains siswa SMP. *JagoMIPA: Jurnal Pendidikan Matematika Dan IPA*, *5*(4), 1335–1347. https://doi.org/10.53299/jagomipa.v5i4.2299

Wang, H. H., Awan, M. K. S., Jenkins, A. R., & Sarkar, S. (2025). Exploring instructional design, occupational interest, and orientation through integrated STEM: A systematic literature review. *Canadian Journal of Science, Mathematics and Technology Education*, *25*(2), 271–291. https://doi.org/10.1007/s42330-025-00362-4

Wardani, N. T., Ismiyati, I., Tusyanah, T., & Sholikah, M. (2025). Evaluating the quality of archival learning programs using the CIPP model : A case study at SMK Negeri 9 Semarang. *Jurnal Pendidikan Progresif*, *15*(01), 516–538. https://doi.org/10.23960/jpp.v15i1.pp

Wu, X. Ben, Sandoval, C., Knight, S., Jaime, X., Macik, M., & Schielack, J. F. (2021). Web-based authentic inquiry experiences in large introductory classes consistently associated with significant learning gains for all students. *International Journal of STEM Education*, *3*. https://doi.org/10.1186/s40594-021-00290-3

Wulanningtyas, M. E., Arfi, & Ramadhan, A. F. (2023). Development of STEM-based learning media using Android and 4D model. *Jurnal Pendidikan MIPA*, *24*(4), 890–900. http://dx.doi.org/10.23960/jpmipa/v24i4.pp890-900

Wulanningtyas, M. E., & Ratnasari, A. S. (2022). Development of STEM-based e-worksheets to improve creative thinking and STEM skills. *Jurnal Pendidikan MIPA*, *23*(4), 1680–1691. http://dx.doi.org/10.23960/jpmipa/v23i4.pp1680-1691

Wyk, L. Van, Ramnarain, U., & Segun, O. (2025). The effects of inquiry-based learning on STEM-related career aspirations of grade 9 natural sciences students. *Research in Science Education*. https://doi.org/10.1007/s11165-025-10285-7

Yesnazar, A., Zhorabekova, A., Kalzhanova, A., Zhuzimkul, B., & Almukhanbet, S. (2024). Methodological system for the formation of meta-subject skills of primary school students in the context of STEM education. *Frontiers in Education*, *9*, 1–8. https://doi.org/10.3389/feduc.2024.1340361

Zendrato, K. V. F., Lase, S. N., Dohona, W. M., Gea, T. Y., Gulo, V. E. N., Telaumbanua, A., Humendru, N. A., Gulo, E. J. J., & Harefa, E. (2024). Efektivitas model pembelajaran project-based learning terintegrasi STEM dalam peningkatan kemampuan literasi sains peserta didik sekolah dasar effectiveness of STEM-integrated project-based learning model in improving science literacy skills of elementar. *Jurnal Riset Pendidikan Dasar*, *XX*(XX), 223–234. https://doi.org/10.30595/jrpd.v5i2.23298

Zulkarnain, T. S., & Tanjung, I. F. (2023). STEM based ecosystem module: An effort to improve students' science process skill. *Jurnal Pendidikan Dan Pengajaran*, *56*(1), 33–44. https://doi.org/10.23887/jpp.v56i1.59516