



Development of arduino-integrated stem worksheets to enhance biology students' creative thinking

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ARTICLE INFO	ABSTRACT
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Keywords: Divergent thinking Innovative learning Learning media Technology integration	Creative thinking among biology education students remains limited, while STEM-based learning has been proposed as one potential approach to address this issue. However, the implementation of STEM-based learning in higher education remains limited, particularly in biology education. This study aimed to develop a STEM-based Student Worksheet integrated with an Arduino DHT11 sensor that is valid, practical, and effective in supporting students' creative thinking skills. This study employed a Research and Development (R&D) approach following the Four-D (4D) development model. The study involved 34 first-year Biology Education C students at Universitas Negeri Surabaya. Data were collected through expert validation, student response questionnaires, learning implementation observations, and pretest-posttest assessments, and were analyzed using descriptive analysis, a paired-samples t-test, and N-Gain analysis. The developed STEM-based Student Worksheet achieved a validity score of 91.56% and a practicality score of 96.16%. Students' average creative thinking score increased from 54.94 in the pretest to 93.40 in the posttest, with a statistically significant difference between the two scores. The overall N-Gain score was 0.86, indicating a very high improvement in students' creative thinking skills. The developed worksheet provides a contextual STEM-based learning resource that integrates authentic environmental investigation, real-time environmental data, and evidence-based solution development to support creative thinking in biology education.

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INTRODUCTION

The development of 21st-century education requires students to master higher-order thinking skills that enable them to adapt to complex problems, generate innovative ideas, and develop appropriate solutions (Liu et al., 2024). Among these competencies, creative thinking is essential because it enables students to generate diverse ideas, explore alternative perspectives, and develop original and meaningful solutions to problems (Anggraini et al., 2019; Guo, 2026). In biology education, creative thinking is particularly relevant because students are expected not only to understand biological concepts but also to investigate biological phenomena, interpret evidence, and propose solutions to real-world biological and environmental problems. Creative thinking is commonly reflected in four indicators fluency, flexibility, originality, and elaboration, which describe students' abilities to generate multiple ideas, consider different approaches, produce novel solutions, and develop ideas in greater depth (Ersoy & Kara, 2026; Martínez et al., 2024).

Empirical studies have indicated that students' creative thinking skills in biology learning still require further development. Pinareswati et al. (2025) found that students' creative thinking skills in ecology learning were predominantly at moderate and low levels, with flexibility representing a weaker aspect of creative thinking than elaboration. Similarly, Puspita et al. (2024) found that Biology Education students demonstrated a moderate level of creative thinking across fluency, flexibility, originality, and elaboration, with originality emerging as the weakest dimension. These findings suggest that biology learning needs to provide learning experiences that allow students to conduct investigations, solve problems, generate multiple ideas, and develop alternative solutions (Haim et al., 2024; Xu et al., 2026). One strategy for fostering students' creative thinking is implementing Science, Technology, Engineering, and Mathematics (STEM) (Preca et al., 2023). STEM-based learning provides students with opportunities to actively investigate contextual problems, explore multiple approaches, generate ideas, design solutions, and evaluate the effectiveness of their proposed solutions through integrated science, technology, engineering, and mathematics activities (Giang et al., 2024; Huang et al., 2025; K. Lin et al., 2021).

STEM-based learning integrates science, technology, engineering, and mathematics through interdisciplinary activities that emphasize applying knowledge to authentic problems and developing practical solutions (Hallström et al., 2023; McLure et al., 2022). Research on STEM-based learning in Indonesia has largely concentrated on primary and secondary education, with comparatively limited attention given to its application in higher education (Nilyani et al., 2023). This pattern is further supported by Farwati et al. (2021), who mapped 154 STEM education studies in Indonesia and found that high school was the most frequently studied educational level, indicating that STEM research has been more extensively investigated at the school level than in undergraduate education. This gap highlights the need for learning resources that can support the implementation of STEM-based learning in higher education. One potential resource is the development of STEM-based student worksheets that provide structured activities for investigation, data analysis, problem solving, and solution development (Saragih & Jayanti, 2025; Wijayanti & Nuraini, 2026).

Previous research has developed STEM-STEAM-based worksheets to support creative thinking skills, yet limitations remain in subject-matter context and technology integration. Khairuna (2023) developed a STEM-based worksheet on the digestive system for 10th-grade high school students to foster creative thinking skills. The study focused on the digestive system and did not integrate environmental data into its investigative activities. Irdalisa et al. (2024) developed a STEAM-based worksheet using project-based learning in ecoprint activities to foster students' creativity and scientific reasoning; the study demonstrated high validity and improvements in students' abilities following instruction. However, the learning process remained focused on the ecoprint project within a specific activity context. Sapriadi et al. (2019) implemented a Higher Order Thinking Virtual Laboratory (HOTVL) in electricity instruction to develop students' creative thinking skills; however, the improvement remained in the moderate category, particularly regarding the aspects of originality and elaboration. These findings indicate that the use of virtual simulation-based technology does not always yield optimal improvements in creative thinking skills, highlighting the need for learning experiences that involve direct interaction with authentic phenomena and data.

These findings confirm that STEM-based worksheets represent a promising instructional innovation. However, their implementation remains largely confined to the school level and rarely integrates real-time, sensor-based measurements. In biology education, the topic of environmental

change offers a relevant context for linking concepts to directly observable environmental phenomena. Parameters such as temperature and humidity can be measured in real-time using a DHT11 sensor connected to an Arduino, thereby generating environmental data suitable for use in investigative and analytical activities (Narayana et al., 2024; Oh, 2025). Integrating the DHT11 sensor with Arduino enables practical environmental measurements during learning activities. Arduino also offers the advantage of easy integration with various sensors via breadboard connections and input modules (Ga & Chang, 2025; Tselegkaridis et al., 2024). The availability of environmental data directly enables students to observe variations in environmental conditions, interpret changes, and use empirical evidence to develop alternative solutions to environmental problems. The use of Arduino technology in classroom learning is relatively accessible to implement, as it can enhance students' motivation and facilitate transversal, interdisciplinary, and multidisciplinary learning (Görgülü Ari & Meço, 2021; Marín-Marín et al., 2024).

Addressing the identified gaps, this study proposes a novel approach by developing a STEM-based student worksheet integrated with Arduino and DHT11 sensors for learning about environmental changes, aimed at fostering the creative thinking skills of biology students. The key innovation lies in the use of real-time temperature and humidity data as an integral component of STEM activities, enabling students to investigate environmental conditions, analyze authentic data, generate alternative solutions, and formulate evidence-based responses. Accordingly, this study aims to: (1) determine the validity of the worksheet based on content, presentation, language, and STEM integration aspects; (2) analyze its practicality based on readability, lesson implementation, and student responses; and (3) evaluate its effectiveness in enhancing students' creative thinking skills based on learning outcomes and the achievement of creative thinking indicators.

METHODS

Research Design

This study employed a Research and Development (R&D) approach using the Four-D (4D) model developed by Thiagarajan et al. (1974). The 4D model consists of four sequential stages: Define, Design, Develop, and Disseminate. This model was selected because it provides a systematic framework for developing, validating, revising, and implementing educational products, thereby ensuring that the developed learning materials are pedagogically appropriate and feasible for classroom implementation (Memon et al., 2024). In this study, the 4D model was used to develop a STEM-based student worksheet on environmental change, integrated with an Arduino-based DHT-11 sensor, to improve undergraduate students' creative thinking skills. The detailed implementation of each stage of the 4D model is described in the Procedure section.

Population and Samples

A total of 34 students from the Biology Education C 2025 program at the State University of Surabaya participated in this study. Participants were selected through purposive sampling to obtain data for evaluating the effectiveness of the STEM-based student worksheet (Astuti et al., 2020). The participants' demographic details are shown in Table 1.

Table 1

Demographic Data Regarding the Population and Sample.

Variable	Category	Frequency	Percentage
Gender	Men	6.00	17.70%
	Women	28.00	82.30%
Total		34.00	100.00%
Age	18 Years Old	24.00	70.50%
	19 Years Old	8.00	23.50%
	20 Years Old	2.00	6.00%
Total		34.00	100.00%

Instrument

Four research instruments were used to collect data for evaluating the validity, practicality, readability, and effectiveness of the developed STEM-based student worksheet. The worksheet's validity was assessed using expert validation sheets completed by a subject-matter expert, a media expert, and a language expert. The validation instrument covered four aspects: content feasibility,

presentation, language, and graphical design. The practicality of the worksheet was assessed using a student response questionnaire and a classroom observation sheet. The questionnaire measured students' perceptions of the worksheet's usability, attractiveness, and usefulness, while the observation sheet assessed the implementation of the learning activities. The worksheet's readability was assessed using the Fry Readability Graph, based on sentence and syllable counts, to determine the appropriateness of its language level for undergraduate biology students. The effectiveness of the worksheet was assessed using a creative thinking skills test administered as a pretest and posttest. The test was developed based on four indicators of creative thinking: fluency, flexibility, originality, and elaboration.

Procedure

This study used a research and development (R&D) method adapted from the 4D model, comprising the define, design, develop, and disseminate stages. The research development flow based on the 4D model is presented in Figure 1.

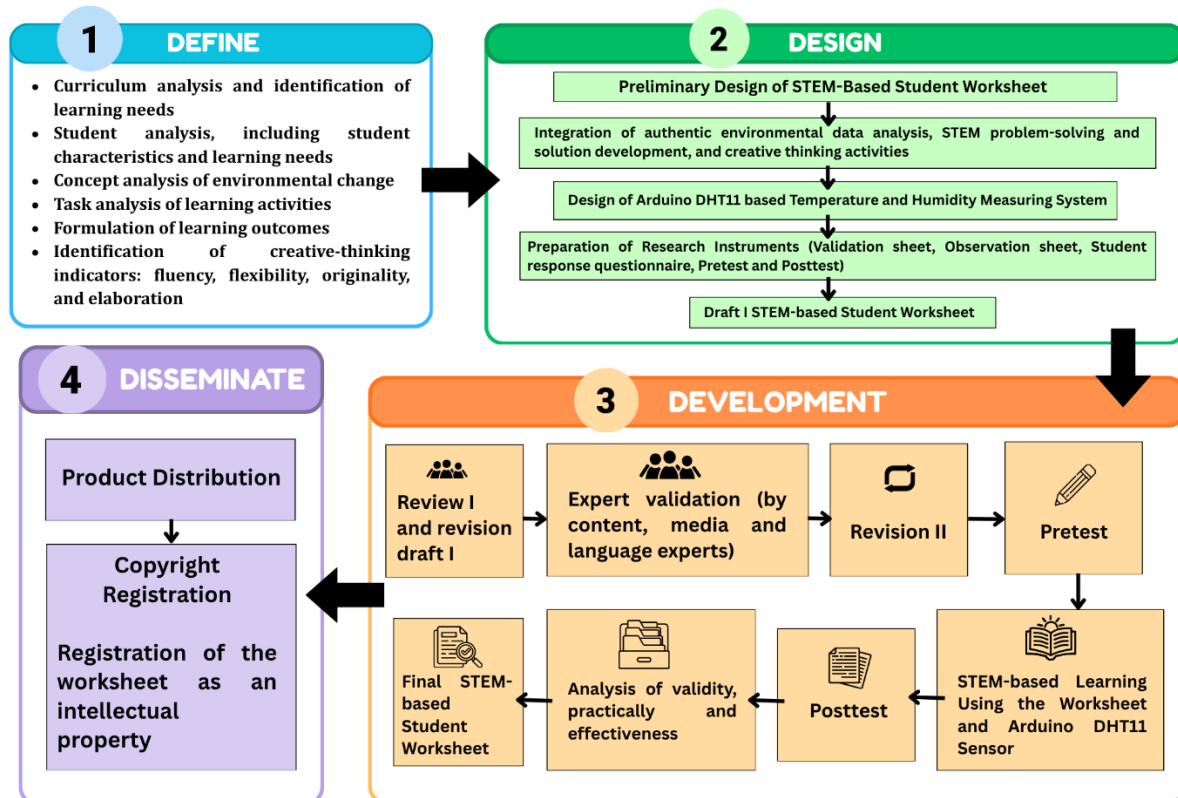


Figure 1. Development Flow of STEM-Based Student Worksheets Using the 4D Model.

Figure 1 illustrates the research procedure following the Four-D (4D) development model. The procedure was designed to develop a STEM-based Student Worksheet that integrates Arduino DHT11 for real-time environmental monitoring with contextual investigation and creative-thinking activities. The distinctive feature of this procedure is the integration of real-time temperature and humidity measurements into STEM learning activities to support authentic environmental data analysis, problem-solving, and solution development. The developed worksheet was subsequently validated, revised, and tested through a limited trial before the final product was prepared for dissemination.

Data Analysis Techniques

After data collection, the raw data were first checked for completeness and consistency. Incomplete or inconsistent entries were identified and reviewed before the data were organized according to the respective instruments. The data were then scored according to the corresponding scoring procedures and entered into SPSS for statistical analysis. Validity data from the expert validation sheets were scored on a 4-point Likert scale (1 = invalid, 4 = very valid). The total score was divided by the maximum possible score, then multiplied by 100 to obtain the validity percentage. The resulting percentages were categorized as invalid (0–20%), less valid (21–40%), quite valid (41–60%), valid (61–80%), or very valid (81–100%) (Riduwan & Sunarto, 2019).

Practicality data from the student response questionnaire and classroom observation sheet were scored using a dichotomous Guttman scale (1 = Yes; 0 = No). The total score was divided by the maximum possible score, then multiplied by 100 to obtain the practicality percentage. The results were categorized as very impractical (0–48%), not practical (49–61%), quite practical (62–74%), practical (75–87%), or very practical (88–100%) (Riduwan & Sunarto, 2019). Readability was assessed using the Fry Readability Graph based on the number of sentences and syllables in a 100-word sample to determine the corresponding readability level (Fry, 1977). The reliability of the 11-item creative-thinking test was assessed using Cronbach's Alpha. The coefficient obtained was 0.682, which was categorized as "Okay" according to Sumintono & Widhiarso (2013), indicating acceptable internal consistency.

For effectiveness analysis, students' pretest and posttest scores were first calculated for the four creative-thinking indicators: fluency, flexibility, originality, and elaboration. The difference score between the posttest and pretest was then calculated for each student. The normality of the difference scores was assessed using the Shapiro-Wilk test. A significance value greater than 0.05 indicated normally distributed difference scores. Because the difference scores met the normality assumption, a paired-samples t-test was performed to determine whether there was a statistically significant difference between the pretest and posttest scores, using a significance level of 0.05. Finally, the magnitude of improvement was determined using the N-Gain score, calculated from the difference between the posttest and pretest scores relative to the maximum possible improvement. N-Gain values were categorized as very low (0.00–0.20), not high (0.21–0.40), fairly high (0.41–0.60), high (0.61–0.80), or very high (0.81–1.00) (Mubai & Irfan, 2023).

RESULTS AND DISCUSSION

The developed STEM-based Student Worksheet integrated environmental change, Arduino-assisted environmental monitoring, and creative-thinking activities within a contextual biology learning framework. Its distinctive feature was the integration of an Arduino Uno with a DHT11 sensor to provide real-time temperature and humidity data for environmental investigation and Temperature Humidity Index (THI) analysis. The worksheet also embedded creative-thinking indicators through activities requiring students to generate multiple ideas, consider alternative approaches, develop original solutions, and elaborate their explanations. These integrated features were designed to provide students with direct learning experiences that connected biological concepts with real-world environmental conditions. The Arduino-based monitoring system used for real-time temperature and humidity measurement is presented in Figure 2.

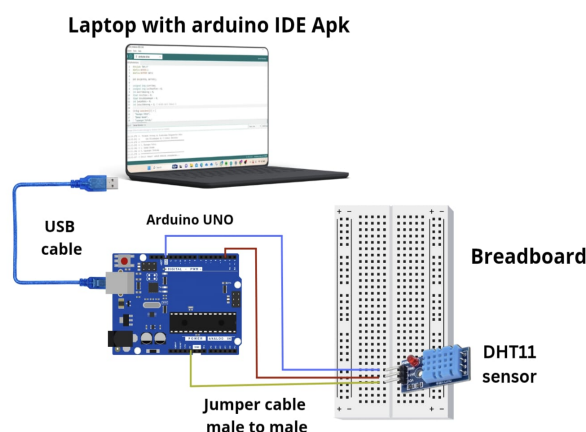


Figure 2. Arduino Uno–DHT11 system for real-time temperature and humidity measurement.

The complete STEM-based Student Worksheet is available at the following link: [STEM-based Student Worksheet](#). The developed worksheet also integrated the four creative-thinking indicators: fluency, flexibility, originality, and elaboration into the STEM learning activities. Each indicator was aligned with specific activities that required students to generate ideas, examine environmental conditions from different perspectives, develop innovative solutions, and elaborate their interpretations using empirical data (Hang, 2024; Hendrik et al., 2022). These activities were designed

to provide students with opportunities to practice each creative-thinking indicator through meaningful STEM-based tasks. The integration of these indicators with the STEM components is presented in [Table 2](#).

Table 2
Student Activities in the Student Worksheet.

Indicator	STEM Aspect	Student Activities
Fluency	Science	Students analyze the case study “Temperature and Humidity Variation in a Home-Yard Environment” and generate two or more questions for further investigation, identify two possible effects of increasing temperature on plant growth, and propose more than one solution to maintain environmental humidity.
Flexibility	Science & Technology	Students identify independent, dependent, and control variables, formulate research questions and hypotheses, compare temperature and humidity relationships across three environmental conditions, and consider different factors that may influence the measurement results, such as wind direction, sensor position, and measurement time.
Originality	Engineering & Technology	Students identify a real environmental problem and develop an innovative sensor-based solution using temperature, humidity, and THI data obtained from the practical investigation. They explain how the proposed solution works and its potential benefits for improving environmental comfort.
Elaboration	Engineering, Technology, Mathematics & Science	Students assemble the Arduino DHT-11 system by connecting the VCC, DATA, and GND pins to the corresponding Arduino Uno connections, collect and organize temperature and humidity data, calculate average values and THI, construct graphs, interpret temperature–humidity relationships using relevant references, and develop recommendations based on THI values. Students also reflect on their learning experiences and the difficulties encountered during the practical activity.

[Table 2](#) shows how the worksheet integrated creative thinking with STEM activities, guiding students from problem identification to data analysis and solution development. The activities encouraged students to generate ideas, consider alternative conditions, develop sensor-based solutions, and interpret empirical data. Thus, Arduino–DHT11 measurements served as an essential part of the creative-thinking process. The quality of instructional worksheets is influenced by the accuracy of their content, the clarity of their presentation and language, and their alignment with the intended learning approach (Erna et al., [2023](#); Saborío-Taylor & Ramírez, [2023](#)). The results of the expert validation are presented in [Figure 3](#).

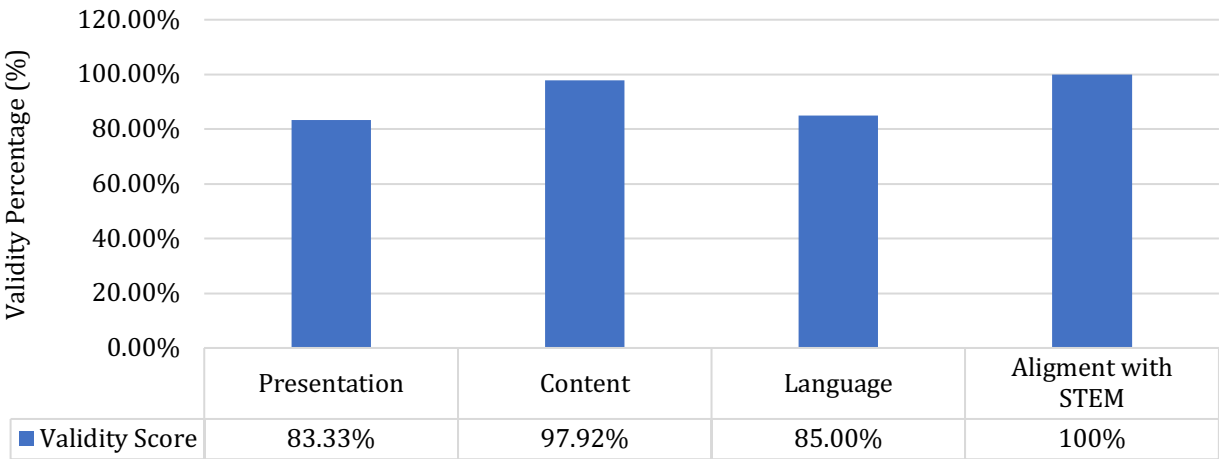


Figure 3. Student worksheet validity results

The expert validation results indicated that the developed STEM-based student worksheet achieved an overall validity average score of 91.56%, placing it in the very valid category. The assessment of the presentation aspect covers coherence, color quality, image quality, and video quality.

The validator recommends improvements regarding audio usage in the tutorial video, specifically by balancing the background music volume and the voiceover to achieve better proportion. The content aspect obtained an average validity score of 97.92% and was categorized as very valid. The assessment of the content aspect covered the accuracy of environmental change concepts, the relevance of the material to the learning objectives, and the suitability of the content with the authentic environmental context presented in the worksheet. The environmental investigation activities incorporated into the worksheet provide opportunities for students to apply biological concepts, analyze authentic environmental data, and develop evidence-based solutions, thereby supporting higher-order thinking and meaningful (Meixner et al., 2024; Prabowo & Paristiowati, 2024). The language aspect achieved an average score of 85.00%, which was categorized as very valid. The assessment of the language aspect covers language usage in accordance with PUEBI, punctuation, and biological terminology that is consistent and easy to understand. The STEM integration aspect achieved an average validity score of 100% and was rated as highly valid. The assessment of this aspect encompassed the integration of science, technology, engineering, and mathematics within environmental investigation activities, the use of Arduino-DHT11, data analysis, and solution development. STEM integration through authentic activities can support creative thinking and problem-solving skills (English, 2023; Kaynar & Kurnaz, 2024). Following the expert validation, the readability of the developed STEM-based student worksheet was assessed using the Fry Readability Graph. The results are presented in Table 3.

Table 3
Recapitulation of the Readability Level of Student Worksheets.

Sample	Pages	Syllables x 0.6	Level
1	2	168.00	13
2	3	167.40	13
3	5	168.60	13

The readability analysis showed that all three text samples were classified at Level 13, indicating that the developed worksheet is appropriate for undergraduate biology students. The consistent readability level across the samples indicates that the language complexity, sentence structure, and terminology used in the worksheet are appropriate for the intended students (Basori, 2023; Hamnell-Pamment, 2024). Appropriate readability can facilitate students' comprehension and reduce unnecessary cognitive load during learning activities (Tarlani-Aliabadi et al., 2022). Overall, the readability results confirm that the worksheet is linguistically appropriate for supporting undergraduate biology students' learning about environmental change.

Following the readability evaluation, the practicality of the developed STEM-based student worksheet was assessed through students' response questionnaires and observations of learning implementation. Student responses reflect users' perceptions regarding the ease of use, usefulness, and suitability of the developed instructional materials during the learning process (Y. Lin & Yu, 2023). The practicality results obtained from the students' response questionnaire are presented in Table 4.

Table 4
Results of the student survey on the practical applicability of STEM-based worksheets.

Aspect	Score (%)	Criteria Interpretation
Presentation	95.58	Very Practical
Content	98.31	Very Practical
Language	94.60	Very Practical
Average	96.16	Very Practical

The overall practicality score of 96.16% indicated that the STEM-based student worksheet was very practical. This result indicates that the worksheet was well received by students and was considered easy to use and suitable for the learning process (Nenggala et al., 2024). This finding was further supported by the results of observations of student activity implementation conducted by the observers, which showed a 100% implementation rate, indicating that all learning activities were implemented as planned. The successful implementation also suggests that the worksheet provided clear guidance for students to follow the learning activities systematically. The sequence of activities allowed students to engage with the learning tasks and complete each stage without disrupting the

planned learning process. In addition, the worksheet integrated instructions with practical activities, enabling students to use the provided materials as guidance during the learning process. However, student responses and observations revealed several qualitative concerns regarding the worksheet presentation, including excessive text, limited visual representation, and difficulties in scanning some barcodes. These concerns indicate that the high level of practicality did not mean that all aspects of the worksheet were equally optimal. Rather, the qualitative feedback identified specific components that could still be improved to provide a more comfortable and engaging learning experience. The excessive text could make important information less accessible, while limited visual representation could reduce the attractiveness of the worksheet. Difficulties in scanning some barcodes could also interrupt students' access to additional learning resources. These findings served as the basis for further revisions to the worksheet to improve its usability and presentation.

The effectiveness of the developed STEM-based student worksheet was evaluated by comparing students' creative thinking scores before and after the learning intervention. The results of the students' creative thinking pretest and posttest are presented in [Table 5](#).

Table 5
Creative Thinking Pretest and Posttest Scores.

Aspect	n	Mean	Std. Deviation
Pre-test	34	54.94	12.444
Post-test	34	93.40	3.289

Students' mean creative-thinking score increased from 54.94 (SD = 12.444) in the pretest to 93.40 (SD = 3.289) in the posttest, representing a mean increase of 38.46 points. The decrease in standard deviation from 12.444 to 3.289 indicates reduced variability in students' posttest scores. The Shapiro-Wilk test showed that the difference scores between the pretest and posttest were normally distributed ($W = 0.978$, $p = 0.721$), satisfying the normality assumption for the paired-samples t-test. Therefore, a paired-samples t-test was conducted to determine whether the observed difference between students' pretest and posttest creative-thinking scores was statistically significant. The results are presented in [Table 6](#).

Table 6
Paired-Samples t-Test of Creative Thinking Scores.

		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
					Lower	Upper			
Pair 1	Pretest - Posttest	-38.456	11.850	2.032	-42.591	-34.321	-18.922	33	0.000

The significant increase in students' creative-thinking scores indicates improved performance following the implementation of the STEM-based Student Worksheet. This improvement may be attributed to learning activities that engaged students in environmental investigation, authentic data analysis, and solution development, requiring them to generate ideas, consider alternative approaches, and elaborate their solutions. The use of Arduino and DHT11 sensors further supported these activities by providing real-time temperature and humidity data, which students interpreted as empirical evidence for analyzing environmental conditions and developing appropriate solutions (Nurcahyo & Afryaningsih, 2024). This finding is relevant to Çoban & Erol (2025) who reported that Arduino-based STEM education improved students' scientific creativity, although the improvement was not statistically significant. In contrast, the present study demonstrated a statistically significant improvement in creative-thinking skills, suggesting that integrating Arduino-based environmental monitoring with contextual environmental investigation and solution development may provide a meaningful context for fostering students' creative thinking. To further examine the patterns of improvement across the four creative thinking indicators, an N-gain analysis was conducted for fluency, flexibility, originality, and elaboration. The results are presented in [Figure 4](#).

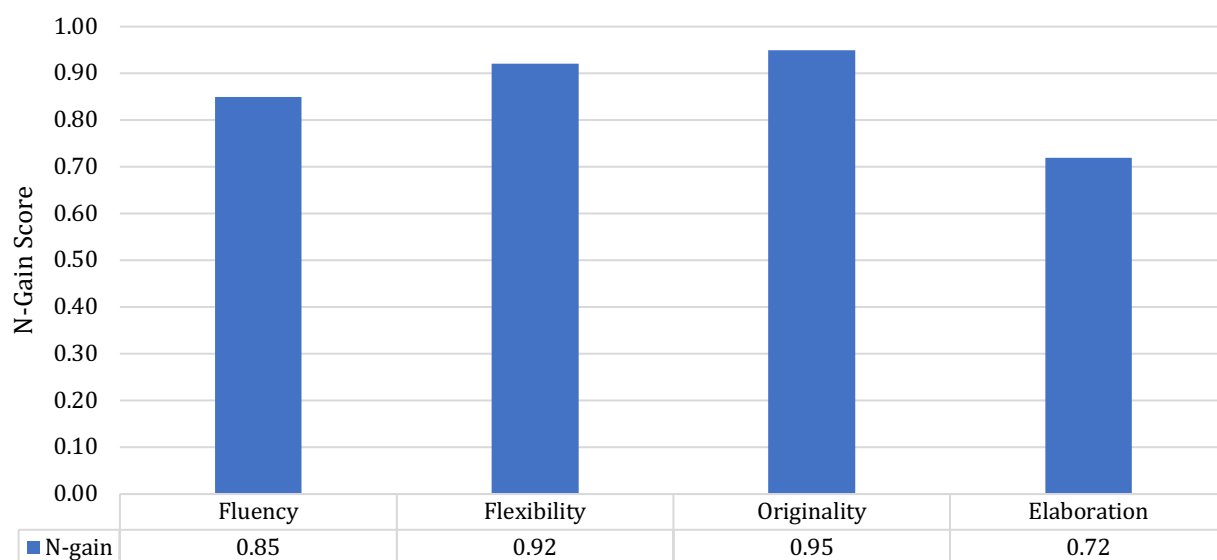


Figure 4. N-Gain Scores for Each Creative Thinking Indicator

Figure 4 presents the N-gain scores for the four creative-thinking indicators. All indicators were classified as high, with originality showing the highest N-gain score (0.95), followed by flexibility (0.92), fluency (0.85), and elaboration (0.72). The overall N-gain score was 0.86, indicating a very high level of improvement in students' creative-thinking skills following the implementation of the STEM-based Student Worksheet. The differences in N-gain scores across indicators suggest that the learning intervention supported multiple dimensions of creative thinking, although the magnitude of improvement varied among the four indicators. This pattern is consistent with constructivist perspectives, which emphasize that active engagement with authentic problems and the integration of prior knowledge with new experiences can facilitate the development of higher-order thinking skills (Almulla, 2023).

The fluency indicator achieved an N-Gain score of 0.85, placing it in the very high category. From a cognitive perspective, activities supporting this indicator involve analysis (C4), particularly through identifying environmental issues, generating multiple questions, considering possible effects, and proposing more than one solution. This improvement aligns with the constructivist paradigm, which emphasizes students' active engagement in constructing knowledge through experience and problem-solving (Ulhaq et al., 2024). In this study, the contextual presentation of environmental issues enabled students to connect prior knowledge to real-world conditions and generate a variety of possible responses (Mulyono et al., 2023; Sigit et al., 2023).

The flexibility indicator achieved an N-Gain score of 0.92, placing it in the high category. This improvement involved analysis (C4) and evaluation (C5), particularly when students identified variables, formulated research questions and hypotheses, and compared relationships between temperature and humidity across three environmental conditions. These cognitive processes enabled students to examine environmental problems from different perspectives and reconsider possible solutions based on empirical evidence. This finding is consistent with the constructivist view that knowledge is developed through active interaction with new experiences and through the reconsideration of existing understanding (Karakuş, 2024).

The originality indicator achieved an N-Gain score of 0.95, placing it in the high category. Cognitively, this indicator involved the process of creating (C6), particularly when students identified environmental problems and developed innovative sensor-based solutions using temperature, humidity, and THI data obtained from the practical investigation. The opportunity to transform empirical environmental data into new solutions enabled students to construct original responses grounded in contextual evidence, consistent with the higher-order creative process of creating (C6) (Tenney et al., 2023).

The elaboration indicator achieved an N-Gain score of 0.72, the lowest among the four creative-thinking indicators. This may be attributed to the high cognitive level of C6 (Creating), in which students were trained to carry out practical activities using the provided tools and materials. Students also

collected and organized temperature and humidity data, calculated average values and THI, constructed graphs, interpreted the relationship between temperature and humidity, and developed recommendations based on the measurement results. Students can achieve higher levels of cognitive development through the systematic application of scaffolding (Kaldaras et al., 2024). In line with Vygotsky's concept, scaffolding helps students progress beyond their respective Zones of Proximal Development. Learning with scaffolding can effectively support students in developing and elaborating their ideas through structured learning activities (Alkair et al., 2023).

The overall evaluation indicates that STEM-based student worksheets enhance creative thinking skills, as evidenced by the N-Gain and the scores across all four indicators, which fall into the "very high" category. As a 21st-century skill, creative thinking enables students to generate ideas, consider various approaches, develop novel solutions, and elaborate on those solutions to address contextual problems (Eshet & Margaliot, 2022). The integration of Arduino and DHT11 sensors provides real-time temperature and humidity data, supporting students in investigating environmental conditions, analyzing empirical evidence, and developing evidence-based solutions. This STEM-based student worksheet was developed to help ensure access to quality multidisciplinary learning in biology education (Indranuddin et al., 2024; Wahono et al., 2023). The research behind this STEM-based worksheet also contributes to addressing gaps in research on STEM at the higher education level, as well as the scarcity of conventional and virtual STEM teaching materials (Rahmawati et al., 2024; Rahmi et al., 2025; Selvia & Tambunan, 2024). This study contributes to technology-based biology learning, specifically on environmental change, by implementing a STEM worksheet integrated with Arduino and DHT11 sensors for real-time applications.

CONCLUSION

This study concludes that the developed STEM-based Student Worksheet integrated with Arduino and the DHT11 sensor is a valid, practical, and effective instructional resource for biology learning. The worksheet supports the development of students' creative thinking by engaging them in authentic environmental investigations, real-time data collection, data analysis, and evidence-based problem solving within a STEM learning environment. The integration of Arduino-based environmental monitoring provides students with opportunities to connect biological concepts with empirical data and technology while developing solutions to contextual environmental problems. These findings demonstrate the potential of sensor-assisted STEM learning to provide meaningful learning experiences that foster creative thinking and active learning. Future research is recommended to implement the worksheet across various biology topics, educational levels, and learning contexts, and to explore additional sensor technologies to further enrich STEM-based learning.

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