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Research Article

Fostering students' creative thinking through inquiry-design-based STEM water purification project

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Clean water scarcity driven by climate change, pollution, and population expansion calls for educational practices that empower students to creatively respond to sustainability challenges. This study investigated the impact of Inquiry-Design-Based Learning integrated within a STEM-oriented water purification project on high school students' creative thinking. A quasi-experimental design involving tenth-grade students compared outcomes between a design-based STEM intervention and a traditional inquiry approach. Students' creative thinking was assessed through four dimensions: fluency, flexibility, originality, and elaboration. The findings show that the design-based STEM intervention led to greater improvements in fluency, flexibility, and originality than conventional inquiry learning. Students engaged in iterative processes of ideation, prototype construction, testing, and refinement, which enabled them to generate and adapt ideas more divergently. By situating problem-solving in a real-world context, designing low-cost water purification devices using recycled materials, the project simultaneously fostered creativity and strengthened awareness of sustainability issues. The novelty of this study lies in demonstrating how iterative design embedded in inquiry explicitly enhances distinct facets of creative thinking in secondary science classrooms. Overall, the findings highlight the potential of design-based STEM pedagogy to cultivate creative problem-solving while supporting global goals for clean water and responsible environmental action.

Keywords: Creative thinking; Inquiry-design-based learning; Iterative design; STEM education; Sustainability education; Water purification project

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1. Introduction

Access to clean water has become an urgent global concern exacerbated by climate change, population growth, and increasing pollution of freshwater sources (O'Dwyer, 2024). According to UNESCO UN-Water (2020), more than two billion people worldwide still lack safe drinking water, a condition intensified by inadequate sanitation systems and escalating contamination. In Indonesia, recurring river pollution, waste mismanagement, and infrastructural limitations heighten the prevalence of waterborne diseases and restrict access to clean water in both urban and rural communities (Bain et al., 2020; Imaduddin & Eilks, 2025). These complex challenges

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underscore the pressing need for educational approaches that empower students, particularly at the secondary school level, to develop the creative, analytical, and problem-solving skills necessary to address sustainability issues (Pereira et al., 2024; Suwono et al., 2023).

STEM-based pedagogies have gained substantial attention for their potential to cultivate higher-order thinking, creativity, and real-world problem-solving when integrated with authentic environmental contexts (Kırıcı & Bakırcı, 2021; Kwon & Lee, 2025). Prior research indicates that STEM projects addressing ecological and community-based issues enhance creativity, adaptability, and innovation (Oyewo et al., 2022; Yunianto et al., 2024). However, although inquiry-based learning [IBL] supports conceptual understanding and scientific reasoning, it often falls short in developing design-oriented creativity without explicit opportunities for iterative engineering engagement (Constantinou et al., 2018; Halawa et al., 2024). This limitation suggests the need for instructional models that bridge inquiry processes with iterative design practice.

Inquiry-Design-Based Learning [IDBL] has recently emerged as a promising framework that integrates scientific inquiry with structured cycles of engineering design (Ignatova et al., 2024; Jolly, 2024). Unlike traditional IBL, which emphasizes conceptual explanation, IDBL embeds iterative phases such as brainstorming, prototyping, testing, redesigning, and reflection within the learning sequence. This integration allows students not only to investigate phenomena but also to generate and refine tangible solutions. Table 1 presents a concise comparison of the learning phases in IBL and IDBL.

Table 1
Systematic comparison of learning phases in IBL and IDBL

Inquiry-Based Learning	*Inquiry-Design-Based Learning*
Observation & Questioning	Observation & Questioning
Hypothesis Formulation	Brainstorming & Initial Design
Investigation/Experimentation	Build, Test, and Analyze Prototype
Data Analysis	Evaluate and Redesign
Conclusion & Communication	Conclusion & Communication

This combined approach supports the generative aspects of creativity (fluency, flexibility, and originality) while maintaining conceptual rigor. Furthermore, project-based STEM learning situated within sustainability issues, such as waste management, renewable energy, and water purification, has been shown to strengthen scientific literacy, civic responsibility, and students' sense of agency in environmental action (Nagamalla et al., 2024; Tan et al., 2023). Nevertheless, empirical research on how IDBL-STEM influences the specific dimensions of creative thinking remains limited, particularly in secondary education and in Global South countries contexts where resource constraints require context-sensitive instructional models.

The relevance of this study extends beyond classroom practice to global policy frameworks. The IDBL-STEM approach aligns with the Sustainable Development Goals [SDGs], especially SDG 4 (Quality Education) and SDG 6 (Clean Water and Sanitation), by engaging students in designing low-cost water purification devices using recycled and locally available materials. Such integration demonstrates how creativity, sustainability, and engineering design can be meaningfully embedded in science education to foster responsible citizenship (Bosevska & Kriewaldt, 2020; Sabancı et al., 2025).

Despite the growing literature on STEM education and project-based sustainability learning, a notable research gap persists: few studies have investigated how the discrete components of IDBL contribute to the four creativity indicators: fluency, flexibility, originality, and elaboration. Most prior research treats creativity as a single construct, leaving uncertainty regarding whether iterative design phases serve as the primary mechanism driving specific creative skill development. Addressing this gap is theoretically and pedagogically important, as creativity is multidimensional and may respond differently to distinct instructional conditions.

To address these issues, this study systematically examines the pedagogical contribution of the

IDBL-STEM model in enhancing creative thinking within a sustainability-oriented water purification project. The following hypotheses were tested:

H1: Students taught using the IDBL-STEM model will demonstrate significantly greater improvements in fluency compared to those taught using the traditional IBL model.

H2: Students taught using the IDBL-STEM model will demonstrate significantly greater improvements in flexibility compared to those taught using the traditional IBL model.

H3: Students taught using the IDBL-STEM model will demonstrate significantly greater improvements in originality compared to those taught using the traditional IBL model.

H4: Students taught using the IDBL-STEM model will demonstrate significantly greater improvements in elaboration compared to those taught using the traditional IBL model.

To evaluate these hypotheses, this study implemented an IDBL-STEM project centered on designing a low-cost water purification system using locally sourced materials. Through a quasi-experimental design, the four dimensions of creative thinking were assessed and compared between IDBL-STEM and traditional IBL groups. By doing so, the study provides empirical evidence on the mechanisms through which iterative design and inquiry integration can foster creative problem-solving in sustainability-oriented science education.

2. Literature Review

2.1. STEM Education and Creativity

STEM education has increasingly emerged as a central pedagogical framework for fostering higher-order thinking and student creativity, largely because it integrates scientific inquiry with authentic and interdisciplinary problem-solving (Lin et al., 2023; Preca et al., 2023). Empirical and meta-analytic evidence demonstrates that STEM interventions, including project-based and inquiry-infused STEM models, consistently enhance scientific process skills, problem-solving abilities, and multiple dimensions of creativity across grade levels (Ortiz-Revilla & Aguilera, 2021). Experimental and quasi-experimental studies further report that STEM activities requiring students to generate tangible solutions, such as design-and-build projects, provide rich opportunities for idea generation (fluency), perspective shifting (flexibility), and the formulation of novel solutions (originality) through iterative cycles of prototyping and testing (Sutaphan & Yuenyong, 2023; Zhan et al., 2023).

Research conducted in secondary school settings also highlights the importance of pedagogical supports such as structured guidance, collaborative group work, and digital visualization tools in strengthening students’ capacity to explore diverse solution pathways, thereby promoting divergent thinking, findings that are consistently noted across field research and systematic reviews. Furthermore, literature on design thinking and design-based learning emphasizes that design competencies (e.g., ideation, prototyping, evaluation) serve as key mediators between STEM learning experiences and creative outcomes (Conradty, 2020; Huang et al., 2022). Thus, creativity is enhanced not simply by implementing STEM projects but by explicitly embedding design elements that structure students’ iterative meaning-making. Recent meta-analyses also suggest that the positive effects of STEM education on creativity are robust yet variable, influenced by factors such as intervention duration, the quality of teacher scaffolding, and the intensity of design-focused activities (Kwon & Lee, 2025). These insights underscore the importance of instructional designs that intentionally prioritize iteration, reflection, and evaluation to maximize creative development in STEM learning environments.

2.2. Limitations of traditional Inquiry-Based Learning

Although Inquiry-Based Learning [IBL] is widely praised for its ability to enhance student engagement, scientific reasoning, and critical thinking, empirical evidence and systematic reviews indicate that IBL has notable limitations when the primary goal is to foster advanced levels of creativity without explicit integration of design-oriented structures (Gya & Bjune, 2021; Larkin & Lowrie, 2023). First, many implementations of IBL follow a relatively linear inquiry sequence (e.g., orientation, exploration, confirmation), which offers limited opportunities for the prototyping and redesign cycles essential for developing fluency, flexibility, and originality (Wan et al., 2022). Second, creative outcomes in IBL depend heavily on the teacher's ability to provide appropriate scaffolding; without sufficient guidance, particularly during ideation and reflection, students tend to generate conventional or insufficiently tested solutions (Halawa et al., 2024). Third, variations in the level of inquiry (open versus structured) significantly influence learning outcomes. Reviews note that open inquiry presents high cognitive demands and often requires substantial time, materials, and teacher expertise, making it difficult to implement effectively in everyday school contexts where instructional time and resources are limited (Borkowski, 2024; Neher-Asylbekov & Wagner, 2023). Fourth, quasi-experimental studies and classroom-based research report inconsistent findings regarding creativity gains; indicators such as elaboration, in particular, tend to develop more slowly, suggesting that IBL alone may not adequately stimulate all dimensions of creativity without incorporating design components that emphasize iterative testing and evaluation (Baran et al., 2021; Elmali & Balkan Kiyici, 2025). Taken together, the literature highlights the need for instructional models that merge the strengths of inquiry, scientific investigation and evidence-based reasoning, with iterative design processes (ideation, prototyping, testing, redesign) to address the limitations of IBL in supporting advanced creativity within STEM classrooms.

2.3. Inquiry-Design-Based Learning as an Integrative Framework

Iterative design, comprising cyclical processes of ideation, prototyping, testing, reflection, and continuous refinement, is a central element that distinguishes the Inquiry-Design-Based Learning [IDBL] model from traditional forms of inquiry. By providing structured opportunities for students to develop and test hypotheses through tangible solutions such as prototypes, iterative design promotes repeated and purposeful engagement in creative thinking (Yüksel, 2025). Empirical evidence and systematic reviews demonstrate that when design components are explicitly embedded within STEM activities, students exhibit enhanced creativity (including fluency, flexibility, and originality) as well as improved design competencies, as they are able to externalize their ideas into artifacts that can be evaluated, modified, and optimized (Schallert et al., 2022; Schoormann et al., 2023).

The iterative process also functions as a cognitive scaffold: guided trial-and-error enables reflective learning, allowing students to learn from prototype failures and use feedback to generate more innovative solutions, mechanisms consistently associated in the literature with divergent thinking and problem reframing (Hallström & Schönborn, 2024). Furthermore, classroom-based studies show that incorporating repeated design tasks increases hands-on engagement and facilitates the transfer of theoretical scientific concepts into practical applications, making learning more authentic and fostering a stronger orientation toward real-world solution-building (Roehrig & Karışan, 2022; Yulianti et al., 2025). However, the literature cautions that the benefits of iteration can only be maximized when teachers provide adequate scaffolding, sufficient time, and material resources to support multiple testing cycles; without these conditions, iterative design risks becoming superficial and insufficient for fostering elaboration or detail-oriented creativity. Therefore, effective IDBL is not merely about adding design tasks to the curriculum but about intentionally crafting learning experiences that enable repeated build, test, redesign cycles supported by formative assessment and structured reflection, so that iterative design truly becomes the driving mechanism of creativity development in STEM education.

2.4. Sustainability-oriented STEM Projects and the SDGs

The integration of sustainability-oriented STEM projects is increasingly recognized as an effective pedagogical strategy for connecting science learning with real-world challenges such as climate change, pollution, and water scarcity (Maqruf et al., 2025; Sabancı et al., 2025). A growing body of research shows that project-based learning centered on authentic environmental issues can enhance students' scientific literacy, ecological awareness, and motivation to engage in sustainable action, while simultaneously strengthening 21st-century skills including creativity and problem-solving (Gürsoy et al., 2023; Luna-Krauletz et al., 2021). This approach aligns closely with several Sustainable Development Goals, particularly SDG 4 (Quality Education), SDG 6 (Clean Water and Sanitation), SDG 9 (Industry, Innovation and Infrastructure), and SDG 12 (Responsible Consumption and Production), which emphasize the importance of locally rooted innovation to address environmental problems.

Empirical studies in educational settings indicate that when students are tasked with designing environmentally friendly technologies, such as simple water filtration systems, energy-saving devices, or waste-management prototypes, they develop not only conceptual understanding but also creative competencies such as ideation, adaptive flexibility, and experimentation (Imaduddin & Eilks, 2025). Sustainability-oriented STEM projects also promote contextualized learning: the use of local materials, community-based problem-solving, and ecological impact analysis enables students to recognize the relevance of science in everyday life, strengthening intrinsic motivation and a sense of agency in addressing global environmental issues (Kırıcı & Bakırcı, 2021; McLure et al., 2022). Moreover, recent literature highlights that designing sustainable solutions through iterative design processes helps students understand the interconnections among social, environmental, and technological systems, competencies that are essential in contemporary science education and explicitly emphasized in global education policies (Wolcott et al., 2021). Therefore, sustainability-oriented STEM projects not only reinforce academic competencies but also cultivate ecological orientations and social innovation, positioning them as a pedagogical framework aligned with the goals of 21st-century sustainable development.

2.5. Unresolved Challenges in Integrating Inquiry and Design

Although numerous studies highlight the potential of science- and engineering-oriented learning to enhance student creativity, recent research indicates that the integration of scientific inquiry and iterative design still faces several unresolved challenges. One major obstacle is that many implementations of Inquiry-Based Learning remain focused primarily on conceptual investigation and do not explicitly integrate design stages such as ideation, prototyping, and redesign (Nahar & Machado, 2025; Ryan & Cole, 2024). As a result, the exploratory experimental aspects essential for creativity do not fully develop. Moreover, although the combination of inquiry and design holds theoretical and pedagogical promise, empirical evidence examining how these two approaches jointly influence specific dimensions of creativity, namely fluency, flexibility, originality, and elaboration, remains limited and inconsistent across educational contexts (Odebiyi, 2023; Saseendran & Thomas, 2025).

Another persistent challenge is the lack of comprehensive documentation of students' creative processes; most studies assess only final outcomes without tracing how ideas evolve through design artifacts, even though analyzing iterative processes is critical for understanding how creativity emerges within science-based design tasks (Sung & Kelley, 2022; Wu et al., 2025). Additionally, sustainability-oriented STEM projects seldom integrate scientific investigation with the development of environmentally friendly technologies, particularly in the context of water purification, which is a key priority under SDG 6. Consequently, the potential of contextualized learning that connects creativity with sustainability-focused action has not been fully explored. These gaps underscore the need for empirical studies that examine how instructional models integrating inquiry with iterative design can support the development of creativity within sustainability-based STEM contexts, while also providing deeper insight into the dynamics of students' creative processes as they engage in authentic problem-solving projects.

3. Methods

3.1. Research Design

The study employed a quasi-experimental method with a non-equivalent pretest-posttest control group design (Leedy & Ormrod, 2021). This design was selected because, in authentic school settings, it is often impractical to randomly assign individual students to different instructional conditions. It is acknowledged that the use of intact classes may introduce potential limitations due to pre-existing group differences. To mitigate this issue, an independent-samples t-test was conducted to confirm baseline equivalence between groups on pretest scores. Furthermore, an Analysis of Covariance [ANCOVA] was employed as the primary statistical technique, which statistically controls for initial group differences and strengthens the validity of inferences regarding the intervention's effects.

Table 2 presents the research design used in this study. The experimental group participated in Inquiry-Design-Based Learning integrated with a STEM project [IDBL-STEM], whereas the control group received traditional inquiry-based learning without the design component.

Table 2
Research design for Non-Equivalent Control Group Pretest-Posttest

Class	*Pretest*	*Treatment*	*Posttest*
Experimental (n =35)	O_1	X_1 (IDBL-STEM Project)	O_2
Control (n = 37)	O_3	X_2 (Traditional IBL)	O_4

Note. O_1 and O_3 represent the pretest of creative thinking skills; X_1 denotes the Inquiry-Design-Based Learning intervention; X_2 represents the traditional Inquiry-Based Learning approach; and O_2 and O_4 indicate the posttest of creative thinking skills.

3.2. Participants

The study was conducted during the second semester of the 2024/2025 academic year at a public senior high school in Padang, West Sumatra, Indonesia. The school was selected purposively based on its readiness to implement innovative STEM-based learning within the national Merdeka Curriculum. The research was situated within a Biology lesson on "Environmental Change and Problems," with a focus on water conservation. To minimize teacher-related variability, both the experimental and control groups were instructed by the same biology teacher.

The participants were tenth-grade students (N = 72) from two intact classes selected through purposive sampling. Class X-A was assigned as the experimental group (n = 35), and Class X-B served as the control group (n = 37). Prior to data collection, ethical clearance was obtained from the institutional ethics committee, and all participants provided informed consent. Data privacy and confidentiality were maintained through anonymization procedures.

Participants ranged in age from 15 to 16 years, with a balanced gender distribution (56% female, 44% male). All students had prior exposure to basic environmental science but had not previously participated in engineering design-based STEM projects. Most participants came from middle-income households, and approximately 20% resided in rural areas surrounding Padang City. This demographic diversity offered a representative context for evaluating how students from varied backgrounds engaged in creative, design-based problem solving. The demographic characteristics of participants are summarized in Table 3.

3.3. Research Instrument

The creative thinking instrument consisted of 10 items, each scored individually on a 1-4 scale based on the detailed rubric (see Appendix A). The total raw score therefore ranged from 10 to 40. This scoring system yielded a total raw score range from a minimum possible score of 10 (a score of 1 on all 10 items) to a maximum possible score of 40 (a score of 4 on all 10 items). For the purpose of statistical analysis and standardized reporting, these raw scores were subsequently

Table 3

Demographic profile of participants (N = 72)

Variable	*Category*	*Experimental Class (n = 36)*	*Control Class (n = 36)*	*Total (N = 72)*	*Test Statistic*	*Effect Size*
Gender	Male	15 (42.9%)	17 (45.9%)	32 (44.4%)	$\chi^2(1) = 0.07$, $p = .788$	-
	Female	20 (57.1%)	20 (54.1%)	40 (55.6%)		
Age (years)	Mean ± SD	15.42 ± 0.47	15.48 ± 0.45	15.45 ± 0.46	$t(70) = -0.54$, $p = .590$	Cohen's $d = 0.13$
Creative Thinking Pretest Score	Mean ± SD	50.89 ± 9.80	50.00 ± 10.51	50.43 ± 10.12	$t(70) = 0.42$, $p = .675$	Cohen's $d = 0.12$

Note. A series of baseline tests confirmed the initial equivalence between the two groups. No statistically significant differences were found in gender distribution or mean age. An independent-samples t-test on creative thinking pretest scores also indicated no significant difference in initial academic ability between the experimental and control groups, $t(70) = 0.42$, $p = .675$. The negligible effect sizes for both age (Cohen's $d = 0.13$) and pretest scores (Cohen's $d = 0.12$) further support the conclusion that the two groups were comparable prior to the intervention.

transformed into a 0-100 scale. This transformation was accomplished using the following standard normalization formula:

$$Final\ score\ (0-100) = \frac{Raw\ score - 10}{Max.raw\ score - Min\ raw\ score} x100$$

This process linearly converts the raw scores to a more intuitive percentage-based scale (0-100) without altering the original distribution of the data.

The instrument’s validity was established through multiple sources of evidence. Content validity was ensured by a panel comprising two experts in biology education and creativity and one senior biology teacher, who reviewed the items for clarity, relevance, and alignment with the learning objectives. Construct validity was supported by the instrument’s strong theoretical grounding in the creative thinking framework proposed by Treffinger et al. (2002), which operationalizes creativity through the dimensions of fluency, flexibility, originality, and elaboration.

The reliability of the instrument was verified through two complementary analyses. For internal consistency, a Cronbach’s alpha coefficient of .87 was obtained, indicating a high level of reliability. To establish scoring objectivity, inter-rater reliability [IRR] was calculated. Two independent raters evaluated a random subset of 25% of the students’ responses (n = 18), yielding an Intraclass Correlation Coefficient [ICC] of .89 (95% CI [.81, .94]), which reflects excellent agreement between raters. The detailed test blueprint, operational definitions of each creative thinking indicator, and the full scoring rubric are provided in Appendix A.

3.4. Research Prosedure

The instructional intervention was implemented over five consecutive sessions (10 x 45 minutes) over three weeks, following the phases of the IDBL model, integrated with a STEM project. This implementation was carried out in two different classes with a total of 72 students. The research procedure comprised three main phases: preparation, implementation, and evaluation.

In the preparation phase, lesson plans, project worksheets, and assessment instruments were developed and reviewed by subject-matter experts to ensure content validity and alignment with curriculum objectives. During the implementation phase, the experimental group engaged in the five iterative IDBL stages: exploration, investigation, development, testing, and reflection, whereas the control group followed traditional inquiry-based learning steps without design prototyping. The evaluation phase involved the administration of pre- and posttests on creative thinking, along with systematic classroom observations to document manifestations of creativity, such as idea generation, design adaptation, and elaboration in project documentation.

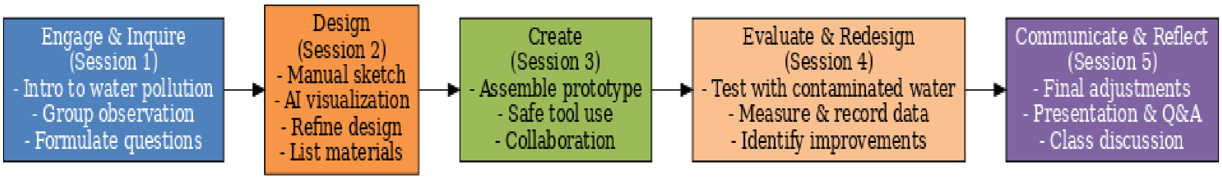
Table 4 presents the syntax of the IDBL model integrated with STEM projects, adapted from Ignatova et al. (2024) and Jolly (2024).

Table 4
Syntax of IDBL model integrated with a STEM project

Phase	*Syntax*	*Indicator*
Exploration	Engage and inquire the problem	Students identify environmental issues (e.g: water pollution) and pose researchable questions.
Investigation	Investigate and brainstorm design	Students explore relevant scientific concepts and generate design ideas.
Development	Create and develop prototype	Students construct water purifier prototypes using recycled materials.
Testing	Evaluate and redesign	Students evaluate prototype performance and collaboratively share findings.
Reflection	Communicate and reflect	Students revise their designs and present the final solution with justifications.

The IDBL-STEM paradigm provides an effective framework for fostering students' creativity by combining inquiry-based learning with the engineering design process. This integration enabled students to understand challenges, design and test solutions, and refine their prototypes using experimental and iterative approaches. Through this process, students developed creativity, innovation, and open-ended problem-solving skills.

Figure 1
Research prosedure of IDBL-STEM intervention



Based on Figure 1, the learning activities in the implementation phase were organized as follows:

3.4.1. Session 1 – Exploration

Students were introduced to the issue of water pollution and plastic waste through a short video and guided discussion. Working in small groups (4-5 members), they observed samples of contaminated water and formulated questions about possible purification methods using available materials. This stage aimed to stimulate curiosity and define the design challenge: developing a functional water purification device from repurposed waste materials.

3.4.2. Session 2 – Investigation

Each group created a manual sketch of their proposed device, labeling its components and filtration sequence. Students then used an AI-assisted image generation tool (e.g., Microsoft Copilot, ChatGPT, or Google Gemini) to visualize their designs digitally. The AI-generated images were compared with manual sketches, and revisions were made before finalizing the design and material list emphasizing the reuse of plastic waste.

3.4.3. Session 3 – Development

Following safety instructions, students constructed their prototypes using materials such as plastic bottles, sand, gravel, and activated charcoal. The teacher provided technical guidance while observing collaboration, creativity, and problem-solving behaviors during the construction process.

3.4.4. Session 4 – Testing

Groups tested their prototypes using standardized contaminated water samples. They recorded filtration time and changes in water clarity, analyzed data collaboratively, and identified design strengths and weaknesses. Based on these findings, students proposed possible improvements to their prototypes.

3.5.5. Session 5 – Reflection

Groups implemented refinements and presented their final products to the class. Presentations included problem statements, design processes (including AI utilization), demonstration of devices, data analysis, and reflections. Each presentation was followed by a question-and-answer session, after which the teacher provided summative feedback and facilitated discussion on sustainability and innovation.

This structured integration of STEM components ensured that each discipline contributed both conceptually and practically. As summarized in Table 5, science provided the theoretical foundation for understanding filtration processes; technology facilitated visualization and data collection; engineering fostered iterative design and refinement; and mathematics supported accurate measurement and evaluation. Beyond disciplinary outcomes, the project aligned strongly with multiple Sustainable Development Goals, specifically SDG 6 (clean water), SDG 9 (innovation), SDG 12 (responsible consumption), and SDG 4.7 (education for sustainable development). This comprehensive approach demonstrates that IDBL-STEM projects can effectively cultivate creative thinking while empowering students as active contributors to sustainability initiatives.

Table 5
Integration of STEM component in water purification project

STEM Component	*Description of Integration*	*Example of Student Activity/Output*	*SDG Link*
Science	Understanding water pollution, filtration mechanisms, and material properties.	Students tested different natural and recycled materials (e.g., sand, charcoal, gravel, plastic waste) for filtration effectiveness.	SDG 6: Clean Water and Sanitation
Technology	Application of tools and AI-based visualization to support design and testing.	Students produced AI-generated sketches and used simple testing instruments to measure water clarity.	SDG 9: Industry, Innovation, and Infrastructure
Engineering	Implementation of the design cycle: identifying problems, designing, prototyping, testing, and redesigning.	Students built and refined purification devices using local recycled materials through iterative testing.	SDG 12: Responsible Consumption and Production
Mathematics	Use of quantitative methods to collect and analyze performance data.	Students calculated flow rates, turbidity reduction, and prototype efficiency.	SDG 4.7: Education for Sustainable Development

3.5. Data Analysis

Data were analyzed using IBM SPSS Statistics version 26**,** with the significance level set at $a = .05$ for all inferential tests. Prior to the main analysis, descriptive statistics (means and standard deviations) were calculated for each variable to provide an overview of the data distribution.

The primary statistical technique employed to test the research hypotheses was a one-way analysis of covariance, conducted separately for each of the four creative thinking indicators: fluency, flexibility, originality, and elaboration. In each ANCOVA model, the posttest score for a given indicator served as the dependent variable, the learning group (IDBL-STEM vs. traditional IBL) was treated as the fixed factor, and the corresponding pretest score was included as a covariate. This procedure allowed for a robust comparison of the intervention's effectiveness by statistically controlling for any pre-existing differences in students' creative thinking abilities.

Prior to conducting the ANCOVA, the assumption of homogeneity of regression slopes was tested and satisfied for all analyses. Additionally, the data met the assumptions of normality and homogeneity of variances, confirming the suitability of the dataset for parametric analysis. To assess the practical significance of the findings, effect sizes were calculated using partial eta squared (partial η^2), following Cohen's (1988) interpretive guidelines (*.01 = small, .06 = medium, .14 = large*). The results of these analyses are reported in the *Results* section.

4. Results

This section presents the results of the data analysis, beginning with the descriptive statistics of students' creative thinking scores, followed by the inferential analyses conducted to test the research hypotheses.

4.1. Descriptive Statistics

The means [M] and standard deviations [SD] for the pretest and posttest scores of each creative thinking indicator were calculated for both the experimental [IDBL-STEM] and control (traditional IBL) groups. The results are summarized in Table 6.

Table 6
Descriptive statistics of creative thinking indicators by group (N = 72)

Indicator	*Group*	*Pretest* $M \pm SD$	*Posttest* $M \pm SD$
Fluency	Experimental (n=35)	13.51 ± 2.87	18.91 ± 4.58
	Control (n=37)	13.08 ± 3.41	15.65 ± 4.98
Flexibility	Experimental (n=35)	12.80 ± 3.11	18.57 ± 4.82
	Control (n=37)	12.32 ± 3.54	15.19 ± 5.09
Originality	Experimental (n=35)	12.06 ± 4.09	18.31 ± 4.29
	Control (n=37)	11.95 ± 3.82	15.46 ± 4.90
Elaboration	Experimental (n=35)	12.51 ± 3.42	18.60 ± 5.48
	Control (n=37)	12.65 ± 3.88	17.03 ± 5.76

As shown in Table 6, both groups had comparable mean scores on the pretest across all four creative thinking indicators, confirming the baseline equivalence reported in the Methods section. Following the intervention, a consistent trend was observed in which the experimental group exhibited higher posttest means across all indicators. Notably, larger mean differences were observed in fluency, flexibility, and originality, suggesting that the IDBL-STEM model contributed positively to these aspects of creative thinking.

However, while the descriptive results indicated a favorable trend for the experimental group, inferential analyses were required to determine whether these observed differences were statistically significant. The results of the ANCOVA tests addressing this question are presented in the subsequent section.

4.2. Hypothesis Testing

A series of one-way analyses of covariance was conducted to examine the effect of the learning model (IDBL-STEM vs. traditional IBL) on students′ posttest scores for each creative thinking indicator, while statistically controlling for their respective pretest scores. The results are summarized in Table 7.

The ANCOVA results revealed a significant effect of the learning model on three of the four creative thinking indicators after controlling for students′ initial abilities. Specifically, students who participated in the IDBL-STEM intervention demonstrated greater improvements in fluency, flexibility, and originality than those in the inquiry-based learning group.

For fluency, the main effect of the learning model was significant, indicating that students in the IDBL-STEM group were able to generate a larger number of ideas when addressing open-ended problems. Similarly, flexibility scores showed a significant difference between groups, suggesting that iterative design processes encouraged students to explore a wider range of perspectives and solution pathways. In terms of originality, the IDBL-STEM model fostered students′ ability to produce novel and unconventional ideas, reflecting the role of design-based inquiry in stimulating innovative thinking.

In contrast, elaboration did not differ significantly between groups. This finding implies that while the design-based approach effectively enhanced students′ idea generation and originality, it had a more limited influence on their ability to refine and develop ideas in detail.

Overall, these results indicate that the IDBL-STEM learning model exerts both statistically and pedagogically meaningful effects on creative thinking, particularly in the dimensions related to divergent idea generation fluency, flexibility, and originality. The non-significant difference in elaboration suggests that extended scaffolding or reflection time may be required for students to deepen and elaborate their creative outputs.

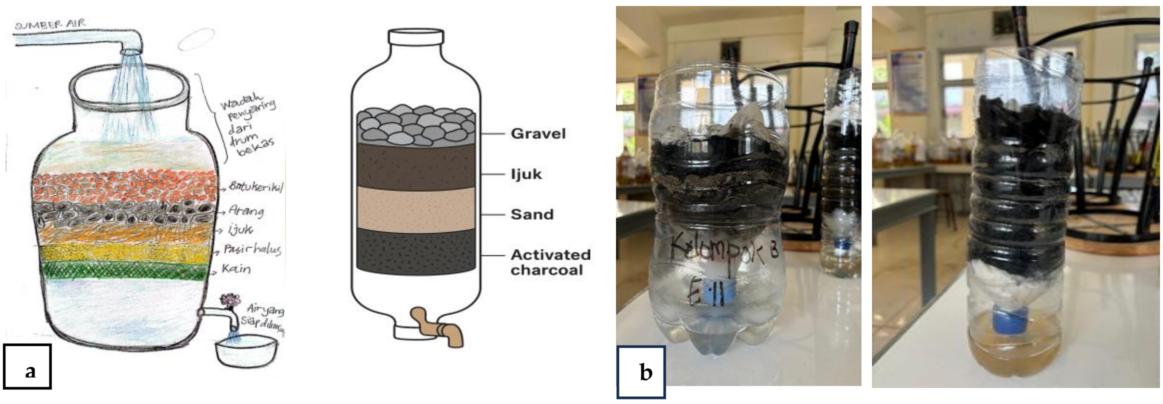
Table 7
Summary of ANCOVA for creative thinking indicators (N = 72)

Indicator	*Source*	*Sum of Squares*	*df*	*Mean Square*	*F*	*p*	*Partial η^2*
Fluency	Pretest (Covariate)	486.29	1	486.29	24.13	< .001	.254
	Group	507.08	1	507.08	25.17	< .001	262
	Error	1390.28	69	20.15			
Flexibility	Pretest (Covariate)	458.07	1	458.07	19.34	< .001	.219
	Group	540.91	1	540.91	22.84	< .001	.248
	Error	1634.61	69	23.69			
Originality	Pretest (Covariate)	269.87	1	269.87	12.89	.001	.157
	Group	235.13	1	235.13	11.23	.001	.140
	Error	1444.60	69	20.94			
Elaboration	Pretest (Covariate)	167.33	1	167.33	5.37	.023	.072
	Group	76.02	1	76.02	2.44	.123	.034
	Error	2148.51	69	31.14			

4.3. Manifestations of Creativity in Project Implementation

Complementing the quantitative findings, qualitative observation data revealed clear manifestations of creative thinking across the five IDBL-STEM phases. Students' creative expressions were documented through classroom observations, design artefacts, and photographs of prototype development. Evidence of creativity was analyzed according to the four indicators (fluency, flexibility, originality, and elaboration) providing deeper insights into how these competencies emerged throughout the project. Representative examples are illustrated in Figures 2 and 3.

Figure 2
Creative outputs in the IDBL-STEM water purification project: (a) student-drawn design concepts and AI-generated, and (b) prototype water purifier before and after design optimization



Following the quantitative analysis, qualitative evidence was collected to illustrate students' creative outputs during the design and development stages of the IDBL-STEM water purification project. Figure 2 presents a series of design concepts and prototypes produced by students throughout the learning process. In Panel A, the initial designs depict AI-generated sketches alongside students' hand-drawn schematics on manila paper. These drawings demonstrate the diversity of ideas and the integration of multiple filtration layers, reflecting the students' ability to produce varied and imaginative solutions to water purification challenges.

Figure 3
The process of developing the water purifier stages by the students

Panel B shows the physical prototypes before and after design optimization. The initial prototype (right) displayed functional limitations, such as incomplete sediment separation and uneven water flow. Through iterative testing and redesign, the optimized prototype (left) incorporated improvements in filter layering and material arrangement, resulting in clearer output water and enhanced filtration performance. These visual outcomes reinforce the quantitative results, emphasizing how iterative design served as a driver of creative thinking during the project.

The implementation of the IDBL-STEM water purification project provided opportunities for students to demonstrate their creative thinking skills through a series of design, prototyping, and testing activities. Data from direct observations, documentation, and artefact analysis were used to characterize the manifestations of creativity according to the four indicators of creative thinking.

Fluency. During the exploration and investigation phases, students displayed high idea fluency by generating multiple design concepts for water purification systems (Figure 3, panels 1-3). They collaboratively brainstormed configurations using combinations of materials such as sand, charcoal, gravel, coconut fiber, and fabric filters. Several groups produced two or more design alternatives before deciding on a final plan. The integration of both manual sketches and digital visualization tools helped students diversify their ideas and express them in different formats.

Flexibility. In the development phase, flexibility was evident as students modified their designs in response to material availability and functional feedback from testing (Figure 3, Panels 2-4). For example, when fine sand was unavailable, some groups replaced it with crushed brick dust or coconut husk, while others altered bottle shapes to improve water flow. These adaptive changes illustrated students' ability to reorganize their approaches and experiment with new ideas under real constraints.

Originality. Originality emerged in distinctive design features and unconventional use of materials (Figure 3, Panels 3 & 6). Some groups added natural components such as dried orange peels to reduce odor, while others cut bottle openings at unique angles to accelerate filtration.

These creative decisions produced ideas that were both novel and functional within the project context.

Elaboration. Elaboration manifested in the detailed refinement of prototypes and supporting documentation (Figure 3, Panels 4-5). Students included additional structures such as sediment pre-filters and secondary outlets for water collection, showing attention to detail and system completeness. While their written reports demonstrated clarity and structural coherence, the degree of elaboration varied across groups, suggesting that not all students achieved the same level of refinement in their designs.

Overall, the qualitative evidence visually and behaviorally substantiates the quantitative findings: the IDBL-STEM learning model fostered strong development in fluency, flexibility, and originality, while elaboration progressed more moderately. The iterative design-test-redesign process served as a catalyst for creative engagement, enabling students to link scientific reasoning with practical environmental innovation.

5. Discussion

This study examined the effects of integrating Inquiry-Design-Based Learning within a STEM project on students' creative thinking compared to traditional Inquiry-Based Learning. The findings provide robust quantitative and qualitative evidence that embedding iterative design cycles within inquiry processes significantly enhances creative thinking, particularly in fluency, flexibility, and originality. These results corroborate previous studies indicating that STEM projects grounded in authentic, real-world contexts can effectively stimulate students' creative cognition and engagement (Akinsemolu & Onyeaka, 2025; Blibech, 2025; Treffinger et al., 2002). Unlike conventional inquiry models that emphasize conceptual understanding and procedural investigation, IDBL explicitly engages students in iterative design, prototyping, and testing. This iterative structure appears to be the key mechanism driving greater creative performance, consistent with design-based learning theory, which posits that cyclical creation and refinement processes promote divergent thinking and innovation (Rusmann & Ejsing-Duun, 2022; Županec et al., 2022).

From a theoretical standpoint, these findings can be interpreted through the creative cognition approach, which views creativity as a structured transformation of existing knowledge into novel configurations through two phases: generation and exploration. The IDBL-STEM framework activates both processes by merging open inquiry with iterative design, enabling students to move fluidly between divergent idea production and convergent idea evaluation. The significant improvements in fluency and flexibility reflect how the design–test-redesign loop scaffolds cognitive flexibility and supports the emergence of multiple and adaptive ideas.

These outcomes align closely with design thinking theory, which identifies empathy, ideation, prototyping, and iteration as critical stages that transform ideas into innovative solutions (Brown, 2009; Hallström & Schönborn, 2024). Within this framework, IDBL encourages students to produce multiple design alternatives and progressively refine them through evidence-based testing. The process thus fosters originality while embodying constructivist principles in which learners actively build understanding through experimentation, collaboration, and reflection (Fachrunnisa et al., 2021; Kenett, 2025). The synergy between inquiry and design enables learners to integrate conceptual reasoning with creative application, illustrating how cognitive and practical creativity converge within the IDBL-STEM context.

The improvement in fluency and flexibility can also be attributed to the open-ended, collaborative nature of the design challenge. Confronted with real-world constraints such as limited materials or prototype inefficiencies, students were encouraged to reorganize ideas, test alternative solutions, and reframe problems creatively. This pattern resonates with the creative problem-solving framework (Treffinger et al., 2012), where fluency and flexibility emerge through continuous exploration, experimentation, and reframing. Similarly, the strong gains in originality suggest that iterative prototyping fosters risk-taking and exploration, conditions essential for producing novel and contextually meaningful ideas. The integration of AI-assisted visualization tools such as Copilot, ChatGPT, or Gemini expanded the students' ideation space and facilitated the visualization of unconventional design alternatives. These tools acted as cognitive extensions that enhanced divergent thinking and creative confidence, aligning with emerging perspectives on the synergy between artificial intelligence and human creativity in STEM education (Fowdur et al., 2024).

In contrast, elaboration showed no statistically significant difference between groups. This indicates that while both IDBL-STEM and IBL allowed opportunities for detailed refinement, elaboration, as a convergent form of creativity, may develop more gradually and require sustained reflection. Previous studies have found that elaboration improves with prolonged engagement and guided feedback (Sung & Kelley, 2022). Thus, extending the duration of IDBL-STEM interventions or embedding structured reflection stages could enhance students' ability to elaborate on their ideas.

Beyond the statistical outcomes, these creative skills manifested clearly in the students' project work. A notable manifestation of originality was the emergence of design ideas incorporating unconventional yet functional local materials, such as coconut husks and palm fiber (ijuk), demonstrating an infusion of cultural knowledge into innovative designs (Runco & Jaeger, 2012; Susilo & Sudrajat, 2020). Flexibility was also a hallmark; when faced with material limitations, students adapted their plans without compromising functionality, reframing challenges as opportunities for innovation (Gya & Bjune, 2021). This aligns with culturally responsive innovation, as described by Lee and Huang (2024), where learners integrate local resources and contextual knowledge into their creative processes. The use of AI-generated sketches alongside manual drawings also exemplifies how technological tools can act as catalysts for creativity (Wu et al., 2025), expanding students' capacity for visual thinking and conceptual exploration. These findings echo Jäggle et al. (2024), who emphasize that sustainability-oriented STEM projects foster resourcefulness, adaptability, and design autonomy competencies essential for creativity in real-world problem solving.

The quantitative and qualitative evidence collectively demonstrate that the IDBL-STEM model bridges scientific inquiry and creative engineering, producing outcomes that are both pedagogically robust and socially relevant. The large effect sizes for flexibility and originality underscore that iterative design promotes adaptive thinking and open-mindedness-skills essential for addressing unpredictable, interdisciplinary challenges (Tan et al., 2023). Meanwhile, the modest gains in elaboration highlight the need for more explicit scaffolding of reflection and documentation to enhance students' depth of creative expression (Spyropoulou & Kameas, 2024). These insights affirm that iterative design not only strengthens conceptual understanding but also cultivates both the cognitive and metacognitive components of creativity (Isaksen, 2023; Kenett, 2025).

Beyond its pedagogical implications, this study demonstrates the potential of creativity-oriented STEM learning to contribute to global sustainability education. By designing and testing low-cost water purification systems, students actively addressed the United Nations Sustainable Development Goals, specifically SDG 4 (Quality Education), and SDG 6 (Clean Water and Sanitation). The project's emphasis on recycling and local materials further aligns with SDG 9 (Industry, Innovation, and Infrastructure) and SDG 12 (Responsible Consumption and Production), reinforcing the notion that education can act as a transformative force for both creativity and sustainability (Husamah et al., 2023; Pandey et al., 2025).

Finally, the implications of this research extend beyond Indonesia. The findings reveal that merging inquiry with iterative design can simultaneously promote creative cognition and sustainability awareness, offering a scalable framework for embedding global competencies in STEM education (Komalasari et al., 2024). The IDBL-STEM approach's emphasis on low-cost, culturally relevant materials enhances its applicability across varying educational and economic contexts. Scaling this model internationally could bridge the gap between environmental awareness and actionable innovation among students. Future studies should employ longitudinal designs to examine whether the gains in creative thinking and sustainability-oriented values persist over time and influence students' future engagement in civic or professional innovation. Expanding this model to address other sustainability challenges, such as waste management, biodiversity conservation, and renewable energy, could further broaden its educational and societal impact. Collaborative cross-national research initiatives may also foster the co-creation of culturally responsive STEM pedagogies, strengthening the global movement toward an education system that is both intellectually rigorous and socially transformative (Setiawan et al., 2025).

In summary, this study provides strong empirical and theoretical evidence that IDBL-STEM is a powerful pedagogical strategy for fostering creativity and sustainability-oriented learning. By engaging students as designers and innovators in solving authentic sustainability problems, the model bridges scientific knowledge and creative application. It offers not only measurable improvements in creative thinking but also a scalable framework for sustainability-driven, future-ready science education.

6. Limitations and Future Research Directions

This study acknowledges several limitations that inform meaningful directions for future research. First, the research was conducted in a single public high school in Padang, Indonesia, which limits the generalizability of the findings. Because creativity development is shaped by cultural, institutional, and resource differences, replication in more diverse educational contexts, across regions, school systems, or countries, is needed to establish the broader applicability of the IDBL-STEM model.

Second, the study relied primarily on quantitative assessments to measure the four dimensions of creative thinking. Although these measures offered robust evidence of the model's effectiveness, the absence of complementary qualitative data, such as classroom observations, reflective journals, or systematic analysis of design artifacts, limited deeper insights into how creativity evolved throughout the iterative design process. Future studies would benefit from adopting mixed-methods approaches to capture these process-level dynamics.

Third, the relatively short duration of the intervention did not allow examination of whether creativity gains persist over time. Longitudinal research is needed to evaluate the durability of learning outcomes. A recommended hypothesis for future investigation is: *Students who participate in IDBL-STEM activities will demonstrate significantly higher retention of creative thinking skills on delayed posttests administered several months after the intervention compared with students taught through traditional IBL.* Testing this hypothesis would clarify whether IDBL supports sustained cognitive growth beyond immediate post-intervention effects.

Finally, although this study included an authentic sustainability-based STEM project aligned with SDG 6, future research should explore additional sustainability contexts, such as climate adaptation, waste management, or renewable energy, to examine whether the relationship between iterative design and creativity is domain-specific or transferable across environmental problem spaces. Cross-context studies would also contribute to understanding how local materials, cultural knowledge, and community-based issues influence students' creative engagement.

Collectively, these limitations highlight the need for broader, deeper, and more process-oriented studies on IDBL-STEM. Addressing these areas will not only refine the theoretical foundations of design-integrated STEM instruction but also advance creativity-centered, sustainability-driven science education.

7. Implications

The findings of this study provide meaningful implications for strengthening creativity-centered STEM education. The demonstrated effectiveness of the IDBL-STEM model highlights its value as a flexible, contextually responsive framework capable of integrating creative thinking, engineering design, and sustainability within science classrooms. As creativity becomes increasingly essential for navigating complex societal challenges, the model offers a practical blueprint for instructional innovation.

At the classroom level, the study suggests that implementing IDBL-STEM requires a shift in the teacher's role from content transmitter to learning facilitator. Rather than directing students toward predetermined outcomes, teachers are encouraged to guide them through open-ended design challenges, iterative testing, and reflective refinement. This shift underscores the importance of professional development that equips teachers with the ability to scaffold divergent thinking, manage iterative project cycles, and provide formative feedback on prototype development, all of which are central to nurturing students' creative capabilities.

The findings also underscore the curricular importance of providing adequate time and structure for iterative design processes to unfold. Meaningful engagement in cycles of building, testing, and redesign cannot be compressed into short instructional periods. Integrating flexible scheduling, thematic project blocks, or extended laboratory sessions enables students to explore ideas more deeply and refine their designs more thoughtfully. These curricular adjustments not only enrich conceptual understanding but also support the broader development of 21st-century creative competencies emphasized in contemporary STEM frameworks.

From a policy standpoint, the IDBL-STEM model aligns well with national and global educational priorities that emphasize creativity, innovation, and sustainability. Because the approach utilizes low-cost, locally sourced, and recyclable materials, it is particularly well suited for resource-limited educational environments. This accessibility positions the model as a viable tool for advancing SDG 4 (Quality Education) while simultaneously contributing to SDG 6 (Clean Water and Sanitation) and SDG 12 (Responsible Consumption and Production). Its scalability makes it relevant for informing curriculum reforms, teacher training programs, and broader educational initiatives aimed at embedding sustainability and creative problem-solving into science education.

Collectively, these implications highlight the broader educational significance of the IDBL-STEM approach. By integrating iterative design and authentic sustainability challenges into science instruction, the model fosters deeper learning, enhances students' creative problem-solving skills, and contributes to the development of future-ready learners. As such, the IDBL-STEM framework represents a promising, scalable pathway for advancing creativity-driven and sustainability-oriented STEM education.

8. Conclusion

This study provides robust empirical evidence for the effectiveness of integrating iterative engineering design processes within a STEM learning framework to foster students' creative thinking. The ANCOVA analyses demonstrated that the IDBL-STEM model produced significantly greater improvements in fluency, flexibility, and originality compared to traditional inquiry-based learning, highlighting its capacity to strengthen the generative dimensions of creativity that are essential for innovation.

The central contribution of this research lies in showing how positioning students as designers and problem solvers, tasked with addressing authentic sustainability challenges, bridges the longstanding divide between scientific understanding and creative application. Situated within constructivist and design-based learning paradigms, the iterative cycle of ideation, prototyping, testing, and redesign enables learners to connect conceptual knowledge with inventive practice, thereby cultivating adaptive, solution-oriented thinking indispensable for 21st-century STEM education.

Beyond its statistical outcomes, the study underscores a broader pedagogical insight: creativity in STEM is most effectively nurtured through learning experiences that are inquiry-driven, hands-on, and grounded in real-world contexts. The IDBL-STEM framework thus serves as a scalable, context-sensitive model capable of advancing both creativity and sustainability competencies in science classrooms. As schools increasingly confront global environmental challenges, the application of IDBL-STEM holds meaningful promise for empowering students to contribute actively and innovatively to local and global problem-solving.

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Data availability: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable requests.

Declaration of generative AI: During the preparation of this work, the authors used ChatGPT to check the grammar of the text and Sci-Space for the purpose of looking for quality literature that can support our research results. The entire manuscript was also reviewed and revised to ensure a consistent academic tone and clarity. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Appendix A. Creative Thinking Test Items and Scoring Rubric

1. Test Blueprint

No.	*Creative Thinking Indicator*	*Item Number*	*Total Items*
1.	Fluency	1, 5, 9	3
2.	Flexibility	2, 6	2
3.	Originality	3, 7, 10	3
4.	Elaboration	4, 8	2
	Total		10

2. Creative Thinking Indicator Definitions

Creative thinking indicators based on Treffinger et al. (2002)

Indicators	*Breakdown of criteria*
Fluency	Students may generate a large number of ideas, solutions, or responses related to a given topic or problem.
Originality	Students are able to produce unique, novel, or uncommon ideas that are different from those of others but still relevant and correct in the context of the problem.
Elaboration	Students are able to develop and expand on ideas, adding detail and depth to them to create more thorough and developed concepts.
Flexibility	Students are able to offer a variety of solutions or approaches to a problem, shifting perspectives and exploring different categories of ideas.

3. Item-Level Scoring Rubric (1-4)

Indicator	*Score*	*Performance Level*	*Scoring Criteria Description*
Fluency	4	Excellent	The student provides **many (>4)** relevant and distinct ideas or answers.
	3	Good	The student provides **several (3-4)** relevant ideas or answers.
	2	Average	The student provides a **few (2)** relevant ideas or answers.
	1	Poor	The student provides only a **single** idea or answer, or the response is irrelevant.
Flexibility	4	Excellent	The response demonstrates ideas from **highly distinct conceptual categories** (e.g., physical filtration, chemical precipitation, biological purification).
	3	Good	The response demonstrates ideas from **several different categories**, though they may be within a similar domain (e.g., various types of physical filtration).
	2	Average	The response focuses on ideas from only a **single conceptual category**.
	1	Poor	The response does not present a clear conceptual category or is irrelevant.
Originality	4	Excellent	The proposed idea is **highly unique, unexpected, and clever**. It demonstrates novel thinking that departs from common examples.
	3	Good	The proposed idea is **somewhat uncommon** and shows some elements of novelty.
	2	Average	The proposed idea is **common, standard, and predictable** (e.g., a simple tube-shaped filter).
	1	Poor	The idea **directly copies an existing example** without modification or is irrelevant.
Elaboration	4	Excellent	The student explains their idea with **exceptional detail, logic, and structure**. The explanation comprehensively covers components, functions, and the process flow.
	3	Good	The student explains their idea with **sufficient detail**, and most parts are clear.
	2	Average	The student provides a **basic explanation**, but many important details are missing.
	1	Poor	The explanation is minimal, unclear, or irrelevant.

4. Example of Raw Score to Scale Score Transformation (0-100 Scale)

Student's Raw Score (Total from 10 items)	*Calculation*	*Final Score (0–100 Scale)*
10 (*Minimum score*)	((10-10) / 30) * 100	0
16	((16-10) / 30) * 100	20
25	((25-10) / 30) * 100	50
34	((34-10) / 30) * 100	80
40 (*Maximum score*)	((40-10) / 30) * 100	100

5. Sample Test Items (Open-Ended Problems)

Fluency: Ability to generate multiple ideas

"In some villages, river water often becomes muddy after heavy rain. Mention as many ideas as possible to make the water cleaner before drinking. The ideas may involve simple tools, natural materials (e.g., palm fibers, coconut husk), or basic technologies. Briefly explain how each idea works."

- **Score 1 (Low):** "Use a cloth as a filter." (The student provides only a **single** idea or answer, or the response is irrelevant).
- **Score 2 (Moderate):** "Use cloth or palm fibers." (The student provides a **few (2)** relevant ideas or answers).
- **Score 3 (Good):** "Use cloth, gravel, sand, and charcoal in layered filtration." (The student provides **several (3-4)** relevant ideas or answers).
- **Score 4 (Excellent):** "Use gravel, sand, activated charcoal, palm fibers, recycled bottles as filter tubes, or even try a simple distillation process." (The student provides **many (>4)** relevant and distinct ideas or answers).

Flexibility: Ability to shift perspective and propose alternatives

*"You design a filter with gravel–sand–charcoal layers. However, when applying it, **sand is not available.** Suggest several **alternatives from different categories** (e.g., palm fibers as a fibrous layer, microfiber cloth, brick powder, coconut husk). Explain how each alternative could replace the function of sand."*

- **Score 1 (Low):** "Replace with soil." (The response does not present a clear conceptual category or is irrelevant).
- **Score 2 (Moderate):** "Replace with brick powder." (The response focuses on ideas from only a **single conceptual category**).
- **Score 3 (Good):** "Replace with brick powder or palm fibers." (The response demonstrates ideas from **several different categories**, though they may be within a similar domain (e.g., various types of physical filtration)).
- **Score 4 (Excellent):** "Use palm fibers as pre-filter, microfiber cloth, cotton, or coconut husk as alternative layers, combined with gravel and charcoal." (The response demonstrates ideas from **highly distinct conceptual categories** (e.g., physical filtration, chemical precipitation, biological purification)).

Originality: Ability to propose unique, uncommon ideas

*"In many households, waste such as coconut husk and palm fibers is often discarded. Design a water purification device that uniquely utilizes **palm fibers (ijuk).** Explain what makes your design different from usual models and why palm fibers can be effective in filtration."*

- **Score 1 (Low):** "Just use coconut husk." (The idea **directly copies an existing example** without modification or is irrelevant).
- **Score 2 (Moderate):** "Put coconut husk inside a bottle as a filter." (The proposed idea is **common, standard, and predictable** (e.g., a simple tube-shaped filter)).
- **Score 3 (Good):** "Use palm fibers as the first layer for coarse particles, followed by sand and charcoal." (The proposed idea is **somewhat uncommon** and shows some elements of novelty).
- **Score 4 (Excellent):** "Design a portable filter using a recycled bottle: palm fibers compacted as pre-filter, coconut husk as additional adsorbent, with a simple valve at the bottom to regulate flow." (The proposed idea is **highly unique, unexpected, and clever**. It demonstrates novel thinking that departs from common examples).

Elaboration: Ability to expand and detail ideas logically

*"Choose your best design idea. Explain it **in detail:** the materials (gravel, charcoal, palm fibers, etc.), the order of layers, approximate size/thickness, assembly steps, and the function of each component. Add a simple **testing plan** (e.g., turbidity test, color, flow rate) and describe possible improvements if the results are not optimal."*

- **Score 1 (Low):** "Use sand and charcoal." (The explanation is minimal, unclear, or irrelevant).
- **Score 2 (Moderate):** "Layer gravel and sand. Water becomes clearer." (The student provides a **basic explanation**, but many important details are missing).
- **Score 3 (Good):** "Layers: gravel, sand, charcoal. Gravel holds big particles, sand filters small particles, charcoal removes odor. Test by observing clarity." (The student explains their idea with **sufficient detail**, and most parts are clear).
- **Score 4 (Excellent):** "Use a recycled bottle as container. Layers: gravel (sediment), palm fibers (trap medium particles), fine sand (filter), activated charcoal (remove odor/color). Water enters from top, exits through a simple tap. Testing: measure turbidity before–after with a turbidity tube and record flow time. If flow is too slow, adjust density of sand or fibers." (The student explains their idea with **exceptional detail, logic, and structure**. The explanation comprehensively covers components, functions, and the process flow).

Appendix B. Classroom Observation Rubric

Dimensions of Creative Thinking Observed in Student Activities

Indicator	*Score 1 (Low)*	*Score 2 (Moderate)*	*Score 3 (Good)*	*Score 4 (Excellent)*
Generating ideas (fluency)	Provide 1 idea	Provides 2-3 ideas with limited variation	Provides ≥ 4 varied and relevant ideas	Provides many diverse and highly relevant ideas
Adapting designs (flexibility)	No adaptation, sticks to one plan	Minor adaptation but limited impact	Several adaptations that improve functionality	Highly adaptive, inovative redesigns to overcome challenges
Using unique elements (originality)	Only conventional elements used	Some unusual elements but not fully relevant	Unique elements that improves design relevance	Highly original, contextually grounded and innovative design choices
Documenting details (elaboration)	Minimal or unclear documentation	Some documentation, incomplete	Detailed documentation with explanations	Thorough, systematic, and logically connected documentation

Appendix C. Student Worksheet for STEM Project: Designing a Low-Cost Water Purifier

A. Project Objectives

1. To understand the principles of water purification using locally available and low-cost materials.
2. To apply the Inquiry–Design–Based Learning (IDBL) approach in solving real-world environmental problems.
3. To foster creative thinking skills (*fluency, flexibility, originality, elaboration*) in the context of STEM learning.

B. Materials and Tools

1. Recycled plastic bottles or containers
2. Gravel / small stones
3. Sand (fine) or substitutes (e.g., brick powder, soil with fine particles)
4. Activated charcoal or natural charcoal
5. Palm fibers (*ijuk*) and/or coconut husk
6. Cloth or microfiber fabric
7. Knife or scissors (teacher-supervised)
8. Measuring cup / turbidity tube (for simple testing)

C. Procedures (IDBL Phases)

1. Exploration Phase (Problem Exploration)
   - Observe: Teacher demonstrates muddy water samples.
   - Discuss: Why is clean water important? What problems arise from dirty water?
   - Define the problem: *"How can we design a simple water purifier using local and low-cost materials?"*
2. Investigation Phase (Planning the Solution)
   - Brainstorm possible materials and structures.
   - Sketch at least two design ideas for your purifier.
   - Select the most feasible design.
3. Development Phase (Prototype Construction)
   - Assemble the water purifier according to your chosen design.
   - Record the materials used and the order of layers.
4. Testing Phase (Evaluation and Redesign)
   - Test the purifier with muddy water.
   - Observe clarity, smell, and flow rate.
   - Record results and compare with expectations.
   - If needed, modify your design and retest.
5. Reflection Phase (Reflection and Sharing)
   - Document the final design with a diagram.
   - Prepare a short explanation of how it works.
   - Share your design with peers and reflect on improvements.

D. Student Reflection (to be filled by students)

1. What was the most challenging part of designing the purifier?
2. Which idea or material in your group was the most creative? Why?
3. If you had more time or resources, how would you improve your design?
4. What did you learn about water purification and about creative problem-solving?