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Authentic Assessment of Biology–Art STEAM through Artificial Waterfall Projects

Penilaian Autentik STEAM Biologi–Seni melalui Proyek Air Terjun Artifisial

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Abstract. STEAM (Science, Technology, Engineering, Arts, and Mathematics) education has gained increasing attention as an interdisciplinary approach fostering creativity, scientific understanding, and problem-solving skills. This study aimed to evaluate students' performance in a Biology–Art integrated STEAM project involving the construction of artificial waterfall models. A quantitative descriptive design was conducted with 43 students. Projects were assessed using eight dimensions: Design Planning, Composition and Aesthetics, Plant Elements, Animal Elements, Creativity, Neatness and Cleanliness, Functionality and Durability, and Project Presentation. Descriptive statistics and the Friedman test were used to analyze student performance across dimensions. Results showed high achievement in all dimensions, with mean scores ranging from 3.16 to 3.63 on a four-point rubric scale. Creativity achieved the highest score ($M = 3.63 \pm 0.49$), while Composition and Aesthetics scored the lowest ($M = 3.16 \pm 0.72$). Significant differences among dimensions were identified ($\chi^2 = 22.15$, $p = 0.0024$), although the small effect size (Kendall's $W = 0.074$) indicated relatively balanced competency development across STEAM domains. These findings show that artificial waterfall projects effectively integrate biological knowledge, artistic expression, and engineering design while developing interdisciplinary competencies.

Keywords: *authentic_assessment; art_integration; biology_education; creativity; STEAM_education.*

Abstrak. *Pendidikan STEAM (Science, Technology, Engineering, Arts, and Mathematics) semakin mendapat perhatian sebagai pendekatan interdisipliner yang mampu mengembangkan kreativitas, pemahaman ilmiah, dan keterampilan pemecahan masalah. Penelitian ini bertujuan untuk mengevaluasi kinerja siswa pada proyek STEAM terintegrasi Biologi–Seni melalui pembuatan model air terjun artifisial. Penelitian menggunakan desain deskriptif kuantitatif yang melibatkan 43 siswa. Proyek dinilai menggunakan delapan dimensi, yaitu Design Planning, Composition and Aesthetics, Plant Elements, Animal Elements, Creativity, Neatness and Cleanliness, Functionality and Durability, serta Project Presentation. Analisis data dilakukan menggunakan statistik deskriptif dan uji Friedman untuk membandingkan kinerja siswa pada setiap dimensi. Hasil menunjukkan capaian yang tinggi pada seluruh dimensi, dengan skor rata-rata berkisar antara 3,16–3,63 pada skala rubrik empat tingkat. Dimensi kreativitas memperoleh skor tertinggi ($M = 3{,}63 \pm 0{,}49$), sedangkan Composition and Aesthetics memperoleh skor terendah ($M = 3{,}16 \pm 0{,}72$). Perbedaan signifikan ditemukan antar dimensi penilaian ($\chi^2 = 22{,}15$; $p = 0{,}0024$), meskipun ukuran efek yang kecil (Kendall's $W = 0{,}074$) menunjukkan perkembangan kompetensi STEAM yang relatif seimbang. Temuan ini menunjukkan bahwa proyek air terjun artifisial secara efektif mengintegrasikan pengetahuan biologi, ekspresi artistik, dan desain rekayasa sekaligus mengembangkan kompetensi interdisipliner.*

Kata Kunci: *asesmen_autentik; integrasi_seni; kreativitas; pembelajaran_biologi; pendidikan_STEAM.*

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1. Introduction

The increasing complexity of twenty-first-century challenges has transformed educational priorities worldwide, shifting the focus from content acquisition toward the development of interdisciplinary competencies such as creativity, critical thinking, collaboration, communication, and problem-solving (1–3). As scientific and technological advancements continue to reshape society, educational systems are expected to prepare learners who can integrate knowledge across disciplines and generate innovative solutions to real-world problems. In response to this demand, Science, Technology, Engineering, Arts, and Mathematics (STEAM) education has emerged as a prominent pedagogical framework that combines scientific inquiry with artistic creativity to promote holistic and meaningful learning experiences(4,5).

STEAM integration offers unique opportunities for students to transform abstract scientific concepts into tangible products through project-based activities. Biology concepts often involve complex structures, relationships, and processes that can be difficult for learners to visualize and understand through conventional instruction alone (6,7). The incorporation of artistic elements into biological learning enables students to communicate scientific ideas through visual representation, model construction, and creative design, thereby facilitating deeper conceptual understanding and sustained engagement. In this study, students developed Biology-Art integrated projects representing plant and animal components, allowing them to demonstrate both scientific understanding and artistic expression. The biological objects represented in the projects included plant structures (*Plantae*) and animal structures (*Animalia*), which served as the primary scientific themes within the learning activities (8,9).

Project-Based Learning (PBL) has been widely recognized as an effective instructional approach for implementing STEAM education because it engages students in authentic tasks requiring investigation, planning, design, construction, and presentation (10–12). Previous studies have reported that STEAM-oriented PBL can enhance students' creativity, scientific literacy, problem-solving ability, and learning motivation. The integration of arts into science learning has been associated with improved visualization skills, innovative thinking, and communication competencies (13–15). Despite the growing body of literature supporting STEAM implementation, empirical evidence regarding students' performance across multiple project assessment dimensions remains limited (16,17).

Most existing studies predominantly evaluate cognitive achievement, conceptual understanding, or students' perceptions of STEAM learning (18,19). Comparatively fewer investigations have examined the multidimensional characteristics of student-produced STEAM projects, particularly aspects such as design planning, aesthetic composition, creativity, functionality, durability, and presentation quality. Current evidence provides only a partial understanding of how students perform across the diverse competencies that STEAM education intends to develop (20–22). This limitation highlights the need for comprehensive assessment frameworks capable of capturing both scientific and artistic dimensions of student performance (23).

Although STEAM learning has increasingly encouraged students to create meaningful products through interdisciplinary projects, assessing these learning outcomes remains a challenge. Traditional assessments, such as written tests or multiple-choice examinations, are effective for measuring conceptual knowledge but often fail to capture how students apply that knowledge in authentic situations. In contrast, authentic assessment evaluates students through meaningful tasks that require them to demonstrate what they know and can do by producing real products or performances. This approach enables teachers to assess not only the final outcome but also the learning process, including planning, creativity, collaboration, communication, and problem-solving. As a result, authentic assessment provides a more comprehensive picture of students' competencies and better reflects the goals of twenty-first-century education.

The use of authentic assessment is particularly relevant in STEAM education because STEAM emphasizes learning through the integration of science, technology, engineering, arts, and mathematics to solve real-world problems. Students are expected to transform scientific concepts into tangible products while making design decisions, applying engineering principles, expressing creativity, and communicating their ideas effectively. These interconnected competencies cannot be adequately evaluated through conventional written examinations alone. Instead, they require an assessment approach that considers multiple aspects of performance simultaneously, including scientific accuracy, functionality, aesthetic quality, originality, and presentation skills. Authentic assessment therefore aligns naturally with the interdisciplinary and product-oriented characteristics of STEAM learning.

The difference between authentic and non-authentic assessment becomes especially clear when evaluating STEAM products. Non-authentic assessment generally measures students' ability to remember information or answer questions in a controlled testing environment. Although such assessments remain useful for evaluating conceptual understanding, they provide limited evidence of students' ability to apply knowledge in meaningful contexts. Authentic assessment, on the other hand, focuses on how students use their knowledge and skills to design, develop, and present products that resemble real-life tasks. In the present study, students constructed artificial waterfall models that integrated biological concepts with artistic design and engineering principles. Evaluating these products required a multidimensional assessment that considered not only scientific correctness but also creativity, functionality, aesthetics, and communication. For this reason, authentic assessment was selected as the most appropriate approach to evaluate the interdisciplinary competencies developed through the Biology–Art integrated STEAM project.

The novelty of this study lies in its multidimensional assessment approach to evaluating Biology-Art integrated STEAM projects. Unlike previous studies that primarily focus on cognitive outcomes or overall project scores, this research systematically examines eight distinct assessment dimensions, namely Design Planning, Composition and Aesthetics, Plant Elements, Animal Elements, Creativity, Neatness and Cleanliness, Functionality and Durability, and Project Presentation. The study employs non-parametric comparative analysis to identify potential differences among these dimensions, thereby providing a more comprehensive understanding of students' strengths and weaknesses in STEAM project implementation.

The present study contributes to the growing literature on interdisciplinary science education and authentic assessment practices. The findings are expected to provide evidence-based insights for educators seeking to design more balanced STEAM learning environments and assessment strategies that foster both scientific competence and creative expression. The purpose of this study is to evaluate students' performance across multiple assessment dimensions in a Biology-Art integrated STEAM project and to determine whether significant differences exist among these dimensions.

2. Methods

Research Design

This study employed a quantitative descriptive design with a non-parametric comparative approach to evaluate student performance across multiple STEAM project assessment dimensions. The design enabled the examination of performance distributions and statistical differences among assessment criteria.

This study was conducted at the Eco Art Corner of Nation Star Academy Senior High School, Surabaya, Indonesia, a learning environment designed to facilitate creative and environmentally oriented project-based activities. The Biology–Art integrated STEAM project was implemented from 11 to 12 March 2026, during which students collaboratively designed and constructed artificial waterfall models integrating biological concepts, artistic elements, and engineering design principles. The completed projects were subsequently presented and evaluated using a multidimensional authentic assessment rubric.

Participants

The participants consisted of 43 students enrolled in a Biology course implementing STEAM-based project learning. Students worked collaboratively to develop project products integrating biological concepts with artistic design elements.

STEAM Project Description

Students were tasked with designing and constructing biology-themed artistic projects representing plant and animal concepts. The project was conducted entirely during regular Biology instructional hours at the Eco-Art Corner, Nation Star Academy Senior High School, Surabaya, Indonesia. This learning space was specifically designed to support project-based and environmentally oriented learning activities, allowing students to collaboratively complete all stages of the project from planning and construction to presentation under the supervision of the Biology teacher. No part of the project was assigned as homework, ensuring equal access to school facilities, materials, teacher guidance, and assessment opportunities for all students. The projects required learners to demonstrate scientific accuracy while incorporating aesthetic, functional, and creative components. The final products were evaluated using a standardized rubric.

The artificial waterfall project was designed as an integrated STEAM activity that combined biological knowledge, engineering design, artistic creativity, technological application, and mathematical reasoning. Scientific concepts were represented through the incorporation of plant and animal elements within a simulated ecosystem. Engineering and technology components were manifested through the design of water circulation systems and structural construction, while artistic aspects were reflected in landscape composition and aesthetic presentation. Mathematical reasoning supported project planning through measurement, scaling, and proportional design considerations. This interdisciplinary integration enabled students to apply knowledge across multiple domains while developing authentic products that reflected both scientific understanding and creative expression (Table 1).

The project was implemented over two Biology class meetings (11–12 March 2026), with the first session dedicated to planning and construction and the second session devoted to project completion, presentation, and authentic assessment.

Table 1. Mapping of STEAM Dimensions and Assessment Indicators in Artificial Waterfall Construction

STEAM Dimension	Project Activities	Related Assessment Dimensions
Science	Identification of plant and animal elements and their ecological relationships within the waterfall ecosystem.	Plant Elements (PE), Animal Elements (AE)
Technology	Use of pumps, electrical components, and supporting equipment to create continuous water circulation.	Functionality and Durability (FD)
Engineering	Designing the waterfall structure, selecting materials, and ensuring stability and water flow efficiency.	Design Planning (DP), Functionality and Durability (FD)
Arts	Arrangement of decorative elements, aesthetic composition, and visual presentation of the model.	Composition and Aesthetics (CA), Creativity (CR)
Mathematics	Determination of dimensions, scale ratios, volume estimation, and spatial organization of project components.	Design Planning (DP), Project Presentation (PP)
Integrated STEAM Outcome	Presentation and explanation of the final product integrating all STEAM components.	Project Presentation (PP), Creativity (CR), Neatness and Cleanliness (NC)

Assessment Instrument

Prior to its implementation, the authentic assessment rubric was subjected to content validation through expert judgment to ensure that each assessment dimension was relevant, clear, and aligned with the objectives of the Biology–Art integrated STEAM project. Three experts, consisting of a biology education lecturer, a STEAM education specialist, and an experienced senior high school Biology teacher, evaluated the instrument using a four-point rating scale (1 = not relevant to 4 = highly relevant). The content validity of the rubric was then analyzed using Aiken's V coefficient. The results, presented in Table 2 and 3, indicate that all assessment dimensions achieved Aiken's V values greater than 0.80, demonstrating that the rubric possessed high content validity and was appropriate for evaluating students' interdisciplinary STEAM project performance.

Student projects were assessed using eight dimensions:

Table 2. Content Validity Results of the Authentic Assessment Rubric Based on Expert Judgment Using Aiken's V

Assessment Dimension	Validator 1	Validator 2	Validator 3	Aiken's V	Interpretation
Design Planning	4	4	3	0.889	Valid
Composition and Aesthetics	4	3	4	0.889	Valid
Plant Elements	4	4	4	1.000	Highly Valid
Animal Elements	4	4	3	0.889	Valid
Creativity	4	4	4	1.000	Highly Valid
Neatness and Cleanliness	4	3	4	0.889	Valid
Functionality and Durability	4	4	3	0.889	Valid
Project Presentation	4	4	4	1.000	Highly Valid
Mean Aiken's V				**0.931**	**Highly Valid**

Note. Three experts evaluated each assessment dimension using a four-point relevance scale (1 = not relevant, 2 = somewhat relevant, 3 = relevant, and 4 = highly relevant). Content validity was determined using Aiken's V coefficient. Values above 0.80 indicate that the assessment dimensions possess acceptable content validity.

Table 3. Assessment Rubric Dimensions for the Biology–Art Integrated STEAM Artificial Waterfall Project

Dimension	Code	Assessment Focus	Description
Design Planning	DP	Project Design	Assesses the completeness and feasibility of project planning, including concept development, organization of materials, and implementation strategy.
Composition and Aesthetics	CA	Artistic Quality	Evaluates visual harmony, balance, color selection, arrangement of components, and overall aesthetic appeal of the project.
Plant Elements	PE	Biological Accuracy (Plant)	Measures the accuracy and appropriateness of plant-related biological representations incorporated into the project.
Animal Elements	AE	Biological Accuracy (Animal)	Assesses the accuracy and relevance of animal-related biological representations included in the project.
Creativity	CR	Innovation and Originality	Evaluates originality of ideas, innovative approaches, and the ability to integrate biology and art creatively.
Neatness and Cleanliness	NC	Product Quality	Measures the precision, tidiness, cleanliness, and overall craftsmanship of the final product.
Functionality and Durability	FD	Engineering Quality	Assesses the usability, stability, functionality, and durability of the project product.
Project Presentation	PP	Communication Skills	Evaluates students' ability to explain project concepts, communicate scientific ideas, and respond to questions effectively.

The assessment rubric was developed to capture the multidimensional nature of STEAM learning outcomes generated through the artificial waterfall project. Eight assessment dimensions were employed to evaluate students' performance comprehensively, covering scientific understanding, engineering design, artistic expression, and project communication. Design Planning and Functionality & Durability assessed students' engineering competencies, while Plant Elements and Animal Elements evaluated the accuracy of biological representations incorporated into the project. Composition and Aesthetics, Creativity, and Neatness & Cleanliness reflected artistic and creative dimensions, whereas Project Presentation measured students' ability to communicate project concepts effectively.

Table 4. Performance Level Criteria for STEAM Project Assessment

Score	Performance Level	General Description
4	Excellent	Demonstrates outstanding achievement, accuracy, creativity, and completeness with minimal or no deficiencies.
3	Proficient	Demonstrates good performance with minor weaknesses that do not significantly affect overall quality.
2	Developing	Demonstrates partial achievement of the expected criteria with several areas requiring improvement.
1	Beginning	Demonstrates limited achievement of the expected criteria and requires substantial improvement.

Data Analysis

Data analysis was conducted using **GraphPad Prism version 10.4.1** (GraphPad Software, San Diego, CA, USA). Descriptive statistics, including the mean, standard deviation (SD), median, quartiles, and range, were computed for each assessment dimension to provide an overview of students' performance. Given that the project assessment utilized a four-point ordinal rubric scale, the assumptions of parametric testing were not considered appropriate. The Friedman test was applied to compare students' performance across the eight STEAM project assessment dimensions. Statistical significance was established at $p < 0.05$ (24–28). Box-and-whisker plots were generated to visualize score distributions, central tendencies, and variability across assessment dimensions (29,30).

3. Result and Discussion

Descriptive Statistics of STEAM Project Performance

Authentic assessment was conducted to comprehensively evaluate students' performance in the Biology–Art integrated STEAM artificial waterfall project. The assessment included project presentation, product evaluation, and direct observation of students' scientific understanding, creativity, and communication skills. Figure 1 presents several authentic assessment activities carried out during the implementation of the project.

Figure 1. Authentic Assessment Activities during the Biology–Art Integrated STEAM Artificial Waterfall Project

Figure 2 illustrates the implementation of the Biology–Art integrated STEAM project through the development and presentation of artificial waterfall models. Students worked collaboratively to design and construct ecosystem-based waterfall structures that integrated biological concepts, artistic aesthetics, and engineering principles. The completed projects were subsequently presented and evaluated through authentic assessment activities involving direct observation, product evaluation, and oral explanations. The assessment process enabled instructors to evaluate multiple competencies simultaneously, including scientific accuracy, creativity, functionality, aesthetics, and communication skills. The visual evidence demonstrates active student engagement throughout the design, construction, and presentation stages, reflecting the interdisciplinary nature of STEAM learning.

Mean scores exceeded 3.0 across all assessment dimensions, indicating a generally high level of achievement in the Biology–Art integrated STEAM project. Creativity achieved the highest mean score (M = 3.63, SD = 0.49), reflecting students' strong capacity to generate original ideas and integrate biological concepts with artistic expression. Neatness and Cleanliness also demonstrated high performance (M = 3.51, SD = 0.55), suggesting careful craftsmanship and attention to product quality throughout the project development process (Figure 1 and Table 5).

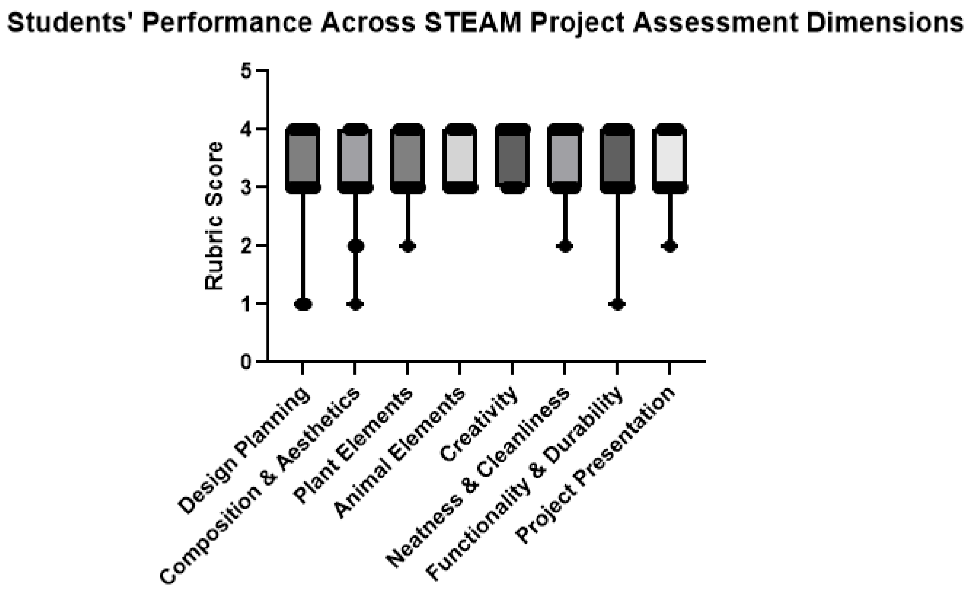

Figure 2. Distribution of Students' Scores Across STEAM Project Assessment Dimensions

Figure 2 presents the distribution of students' performance across the eight assessment dimensions evaluated in the Biology–Art integrated STEAM artificial waterfall project. The boxplot analysis indicates that most scores were concentrated between rubric levels 3 and 4, suggesting that the majority of students achieved proficient to excellent performance across all dimensions. Median scores were generally positioned at 3 or 4, reflecting consistently high levels of achievement.

Creativity exhibited one of the most favorable score distributions, characterized by a high median score and a relatively narrow interquartile range, indicating both strong performance and consistency among students. Similar patterns were observed for Plant Elements, Animal Elements, and Neatness and Cleanliness, suggesting that students effectively integrated biological concepts and maintained high-quality project execution.

Greater variability was observed in Design Planning and Composition and Aesthetics, as evidenced by wider score distributions and the presence of lower-value observations. These findings indicate differences in students' abilities to develop comprehensive project plans and achieve aesthetically balanced designs. Functionality and Durability also displayed several lower scores, suggesting that some students encountered challenges related to structural stability and operational performance of the artificial waterfall models.

Descriptive statistics were calculated to provide an overview of students' performance across the eight assessment dimensions of the Biology–Art integrated STEAM artificial waterfall project. The mean and standard deviation values were used to examine achievement levels and score variability for each dimension. The results are presented in Table 5.

Table 5. Descriptive Statistics of Student Achievement in Biology–Art Integrated STEAM Projects

Aspect	Mean ± SD
Design Planning (DP)	3.19 ± 0.93
Composition & Aesthetics (CA)	3.16 ± 0.72
Plant Elements (PE)	3.42 ± 0.54
Animal Elements (AE)	3.44 ± 0.50
Creativity (CR)	3.63 ± 0.49
Neatness & Cleanliness (NC)	3.51 ± 0.55
Functionality & Durability (FD)	3.40 ± 0.62
Project Presentation (PP)	3.40 ± 0.54

Composition and Aesthetics yielded the lowest mean score (M = 3.16, SD = 0.72), indicating greater variation in students' ability to organize visual components and achieve aesthetic balance. Design Planning exhibited a similarly lower mean score (M = 3.19, SD = 0.93) and the largest standard deviation among all dimensions, suggesting considerable heterogeneity in students' planning and project organization skills.

Score distributions visualized through boxplot analysis revealed that most observations were concentrated within rubric levels 3 and 4, indicating that the majority of students attained proficient to excellent performance levels. Several lower-value outliers were observed in Design Planning, Composition and Aesthetics, and Functionality and Durability, indicating that a small proportion of students encountered difficulties in translating initial design concepts into well-structured and functional project products. The relatively narrow interquartile ranges observed in Creativity, Plant Elements, and Animal Elements suggest a more consistent level of achievement across students in these dimensions.

Comparative Analysis of Assessment Dimensions

Differences in student performance across the eight assessment dimensions were examined using the Friedman test, a non-parametric alternative to repeated-measures analysis of variance suitable for ordinal data. The analysis was conducted to evaluate whether the dimensions assessed within the Biology–Art integrated STEAM artificial waterfall project exhibited statistically different performance distributions. The results are summarized in Table 6.

Table 6. Distribution of Students' Performance Levels Based on the Authentic Assessment Rubric

Performance Level	Score Range	Frequency (n)	Percentage (%)
Excellent	3.50–4.00	17	39.53
Proficient	2.50–3.49	26	60.47
Developing	1.50–2.49	0	0.00
Beginning	1.00–1.49	0	0.00
Total		**43**	**100.00**

Before comparing students' performance across the eight assessment dimensions, the overall achievement level was classified according to the performance criteria presented in Table 3. As shown in Table 6, students achieved an overall mean score of 3.39, corresponding to the Proficient performance level. The majority of students (60.47%) were classified as Proficient, while 39.53% reached the Excellent level. No students were categorized as Developing or Beginning, indicating that all participants achieved at least the expected level of performance in the Biology–Art integrated STEAM project. These findings suggest that the authentic assessment rubric effectively captured students' interdisciplinary competencies, with most students demonstrating consistent achievement across scientific understanding, engineering design, artistic creativity, and project presentation.

Differences in student performance across the eight assessment dimensions were subsequently examined using the Friedman test, a non-parametric alternative to repeated-measures analysis of variance appropriate for ordinal data. The analysis was conducted to determine whether statistically significant differences existed among the assessment dimensions of the authentic assessment rubric. The results are presented in Table 7.

Table 7. Friedman Test Results

Parameter	Value
Number of Students	43
Number of Dimensions	8
Friedman Statistic (χ^2)	22.15
p-value	0.0024
Kendall's W	0.074
Effect Size Interpretation	Small
Significance Level	0.05

The Friedman test revealed statistically significant differences among the eight assessment dimensions ($\chi^2 = 22.15$, $p = 0.0024$). The corresponding Kendall's coefficient of concordance indicated a small effect size ($W = 0.074$), suggesting that the observed differences among dimensions were statistically significant but relatively limited in magnitude. These findings indicate that students demonstrated generally balanced achievement across STEAM competencies, although certain dimensions, particularly Creativity and

Neatness and Cleanliness, tended to achieve higher scores than Design Planning and Composition and Aesthetics.

Discussion

Mean scores exceeding 3.0 across all assessment dimensions indicate that students achieved proficient to excellent performance throughout the Biology–Art integrated STEAM artificial waterfall project. The consistently high achievement suggests that the project provided opportunities for students to integrate biological knowledge, artistic creativity, engineering design, and communication skills within a single learning experience. Such outcomes reflect the capacity of STEAM-based project learning to facilitate interdisciplinary competency development through authentic and product-oriented activities. These findings are consistent with previous studies demonstrating that STEAM-oriented Project-Based Learning promotes the integration of scientific knowledge with creativity, collaboration, and problem-solving through authentic learning experiences (1,10,36). Furthermore, authentic project-based activities encourage students to apply concepts across multiple disciplines while producing meaningful products, thereby supporting the development of twenty-first-century competencies beyond conceptual understanding alone (5,11).

Statistically significant differences were identified among the assessment dimensions (Table 7) ($\chi^2 = 22.15$, $p = 0.0024$). Kendall's coefficient of concordance indicated a small effect size ($W = 0.074$), suggesting that the observed differences were relatively limited despite reaching statistical significance. This finding indicates that students developed competencies across the STEAM domains in a relatively balanced manner. Similar findings have been reported in previous studies, which showed that project-based STEAM learning promotes the simultaneous development of scientific understanding, creativity, engineering design, and communication skills through authentic interdisciplinary activities (1). The small effect size therefore suggests that the artificial waterfall project effectively facilitated integrated competency development rather than emphasizing a single aspect of student performance.

Creativity achieved the highest mean score ($M = 3.63 \pm 0.49$) (Table 4), reflecting students' ability to generate original ideas and translate biological concepts into innovative visual representations. The construction of artificial waterfall ecosystems required students to integrate ecological knowledge, artistic design, and engineering principles, thereby encouraging divergent thinking and creative problem-solving. This finding suggests that the Biology–Art integrated STEAM project provided meaningful opportunities for students to express creativity while applying scientific concepts in authentic contexts. Similar findings have been reported by (4), who found that STEAM-integrated Project-Based Learning significantly enhances students' creative thinking and cognitive learning outcomes. Likewise, (10) reported that project-based STEAM activities promote creativity by engaging students in authentic design challenges that require innovation, collaboration, and interdisciplinary problem-solving. The high creativity score observed in this study supports the view that authentic STEAM projects effectively foster creative competencies alongside scientific understanding.

Neatness and Cleanliness also demonstrated high achievement ($M = 3.51 \pm 0.55$), suggesting that students paid considerable attention to craftsmanship and the overall quality of their project products. The construction of a visible and functional artifact encouraged students to carefully organize materials, refine structural details, and improve the visual presentation of the artificial waterfall model. This finding indicates that authentic project-based assessment not only evaluates conceptual understanding but also promotes students' responsibility for producing high-quality work. Similar findings were reported by (31), who demonstrated that rubric-based assessment improves students' performance by clarifying quality expectations and encouraging self-regulated learning. Likewise, (32) found that analytical rubrics support higher-quality creative products by guiding students to pay greater attention to precision, aesthetics, and craftsmanship throughout the design process. Therefore, the high achievement in this dimension reflects the effectiveness of authentic assessment in encouraging students to produce scientifically accurate and well-crafted STEAM products.

Plant Elements (M = 3.42 ± 0.54) and Animal Elements (M = 3.44 ± 0.50) (Table 4) recorded consistently high scores, indicating the effective incorporation of biological concepts into the project designs. Representing living organisms within the artificial waterfall ecosystem required students to apply knowledge of biodiversity, ecological interactions, and environmental characteristics. The integration of artistic and engineering components did not diminish the scientific quality of the projects; instead, biological concepts remained clearly embedded within the final products, demonstrating successful interdisciplinary knowledge transfer. This finding is consistent with previous studies reporting that STEAM-integrated biology learning enhances students' conceptual understanding by enabling them to apply scientific knowledge in meaningful and authentic contexts (4,6,7). Furthermore, the use of project-based STEAM activities encourages students to connect biological concepts with real-world applications, thereby strengthening both conceptual mastery and scientific communication (18).

Composition and Aesthetics (M = 3.16 ± 0.72) and Design Planning (M = 3.19 ± 0.93) exhibited comparatively lower mean scores and greater variability. Design Planning showed the largest standard deviation among all dimensions, indicating considerable differences in students' abilities to organize project procedures, allocate resources, and anticipate implementation challenges. Likewise, aesthetic composition requires competencies related to visual balance, proportion, harmony, and spatial organization, which are not commonly emphasized in conventional biology instruction. Similar findings have been reported by (23), who noted that design thinking and visual design skills require sustained practice and iterative learning experiences before students can demonstrate consistent performance. (33) also emphasized that design-based STEAM learning strengthens these competencies gradually through repeated cycles of planning, prototyping, evaluation, and refinement. Therefore, the greater variability observed in these dimensions suggests that students may benefit from additional instructional scaffolding in design thinking and visual literacy to support more balanced competency development.

Functionality and Durability (M = 3.40 ± 0.62) demonstrated moderate variability, reflecting the challenges associated with implementing engineering concepts in the artificial waterfall project. Developing a functional model required students to consider water circulation, structural stability, material selection, and long-term durability simultaneously. The relatively lower performance observed in several projects suggests that engineering-related tasks were more demanding than biological representation or artistic design. Similar findings have been reported by (8), who found that engineering design is one of the most challenging components of

STEAM projects because it requires iterative testing, revision, and optimization before students achieve functional solutions. Likewise, (34) emphasized that repeated opportunities for prototyping and design refinement are essential for improving students' engineering thinking and problem-solving skills in project-based STEAM learning. Therefore, incorporating multiple design iterations and formative feedback may further enhance students' performance in this assessment dimension.

Score distributions concentrated between rubric levels 3 and 4 indicate that most students achieved satisfactory to excellent performance across assessment dimensions. Relatively narrow interquartile ranges observed in Creativity, Plant Elements, and Animal Elements suggest greater consistency of achievement among students (31,35,36). Wider distributions in Design Planning, Composition and Aesthetics, and Functionality and Durability indicate that these dimensions were more sensitive to individual differences in design thinking, visual literacy, and engineering probl em-solving skills (32,37).

Performance patterns observed across assessment dimensions highlight the effectiveness of the artificial waterfall project as a STEAM learning activity capable of integrating scientific understanding, creativity, engineering design, and communication skills (38,39). Strong achievement in creativity and biological representation demonstrates successful interdisciplinary integration, whereas variability in planning, aesthetics, and functionality identifies dimensions requiring additional instructional scaffolding. Structured design-thinking activities, visual literacy in struction, and iterative engineering practices may contribute to more balanced competency development in future STEAM-based biology learning environments (33,34,40).

4. Conclusion

Biology–Art integrated STEAM learning through artificial waterfall construction effectively facilitated the development of interdisciplinary competencies, as evidenced by mean scores exceeding 3.0 across all assessment dimensions, indicating generally proficient to excellent performance. Creativity emerged as the highest-performing dimension, followed by Neatness and Cleanliness, reflecting students' ability to integrate scientific understanding with innovative design and high-quality product development, while strong achievement in Plant and Animal Elements demonstrated successful incorporation of biological concepts into project outcomes. Significant differences were identified among assessment dimensions (χ^2 = 22.15, p = 0.0024); however, the small effect size (Kendall's W = 0.074) suggests relatively balanced competency development across the STEAM framework. Greater variability in Design Planning and Composition and Aesthetics indicates the need for enhanced instructional support in design thinking, visual literacy, and project organization. The findings highlight the potential of artificial waterfall projects as authentic STEAM learning experiences that connect biology, art, and engineering while fostering creativity, scientific understanding, and interdisciplinary problem-solving skills, with future research needed to explore their long-term effects on scientific literacy and environmental competency development.

5. Limitations and Future Research

This study has several limitations that should be considered when interpreting the findings. First, the study involved a relatively small sample of students from a single senior high school, which may limit the generalizability of the results to other educational contexts. Second, the authentic assessment focused primarily on students' project products and performance during the implementation of the Biology–Art integrated STEAM activity, without examining the long-term effects on students' conceptual understanding, creativity, or other twenty-first-century skills. Third, the study employed a quantitative descriptive design; therefore, students' learning experiences, perceptions, and challenges during the project were not explored in depth.

Future research is recommended to involve larger and more diverse samples across different schools and educational levels to improve the generalizability of the findings. Further studies may also adopt mixed-methods or experimental designs to investigate how authentic assessment influences students' learning processes, creativity, scientific literacy, problem-solving, and engineering design skills over time. In addition, examining the reliability and applicability of the authentic assessment rubric in different STEAM contexts would provide further evidence of its effectiveness as an assessment framework for interdisciplinary learning.

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