Reception and Interpretation of STEAM Meta-Artworks: How Non-Art Major Graduate Students Perceive the Role of Art Through Exhibition Appreciation and Artist Commentary

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Abstract— **This exploratory case study describes the internal processes through which non-art major graduate students interpret and assign meaning to art within a STEAM education context. Focusing on the multimodal exhibition "Art in Life," open-ended responses from ten graduate students were collected before and after an oral commentary by the artist and analyzed using the SCAT method. Regarding artwork reception (RQ1), some participants' descriptions suggested that familiar visual elements made unfamiliar scientific themes feel closer, and some described shifts in their pre-existing perceptions of art. Regarding perceptions of STEAM and Art (RQ2), some participants viewed STEAM as a practical approach for integrating diverse knowledge, and some recognized Art as a non-verbal medium for communication, while pointing out structural difficulties in grasping the vast scope of STEAM. Overall, the findings suggest that some non-art-major graduate students used familiar visual and everyday references as possible entry points for interpreting STEAM-related artworks. Following the artist's commentary, participants incorporated explanatory content into their descriptions, although the differences in prompt wording limit direct comparisons between the two stages. The findings also indicate potential tensions between interpretive guidance and openness in art appreciation. These exploratory results provide insights into how meta-artworks may serve as boundary objects for initiating reflection on STEAM, while highlighting the need for further investigation.**

Keywords— STEAM Education, Boundary Objects, Entry Points, SCAT Analysis

I. INTRODUCTION

A. Background and Issues

In recent years, global society has entered a VUCA era accompanied by rapid technological innovation and value diversification. Addressing these transformative shifts, the Organization for Economic Co-operation and Development (OECD) presented the "Learning Compass 2030," defining "Student Agency"—where learners set autonomous goals and take initiative-taking approaches to society—and "Creating New Value" as foundational competencies [1]. In parallel, Japan is rapidly advancing educational reforms to realize the super-smart "Society 5.0" [2]. In 2021, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) emphasized developing interdisciplinary problem-solving and value-creation capabilities transcending the humanities-sciences divide, strongly positioning STEAM (Science, Technology, Engineering, Arts, Mathematics) education across national curricula [2]. Furthermore, the "Classrooms of the Future" proposal spearheaded by the Ministry of Economy, Trade and Industry (METI) strongly advocates for the "STEAM-ification of learning." This approach takes the learner's intellectual curiosity as its starting point and utilizes design thinking to enable students to solve authentic societal challenges collaboratively while iteratively traversing between inquiry ("knowing/input") and creation ("making/output") [3].

While policy-driven initiatives have made progress, several theoretical and practical considerations remain to be explored in academic research. First, the "A" in STEAM education carries a dual meaning, which often causes confusion in how it is interpreted. Prior research has clarified the ongoing conflation between "ART," which emphasizes sensibility and aesthetic self-expression, and "ARTS" (referring to liberal arts and general education), which involves a multifaceted understanding of human and social contexts including philosophy, ethics, history, and economics. This ambiguity in interpretation has generated confusion and pedagogical bias among practitioners and learners, particularly in the implementation of STEAM education in Japan [4], [5]. Second, there is a need to overcome the "one-sided instrumental" integration of STEM and Art. Mejias et al. (2021) pointed out that many STEAM practices remain trapped in "one-sided instrumentalism," wherein Art is applied merely as an efficient means or illustration/decoration to make STEM easier to understand, or conversely, where technology is used merely as "art supplies" for artistic expression [6]. To ensure that the autonomy and critical inquiry of Art are not compromised, they advocated a shift toward a "mutually instrumental and pedagogical relationship" in which both domains collaborate on an equal footing (co-equal partnership), transforming each other's learning and conceptual understanding [6]. Third, there is a need for empirical research on multimodal learning support and the role of "boundary objects" in STEAM education. Okumoto (2024) demonstrated that the "narrativization"

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process characteristic of painters can contextualize cutting-edge biological concepts within everyday life [7]. While Okumoto highlights multimodal meaning-making, recent STEAM research by Vartiainen (2025) introduces the concept of "boundary objects"—such as imagination and imaginative practices—that bridge learners' everyday cultural practices with the cultural practices of science [8]. However, how multimodal meta-artworks act as boundary objects to mediate cross-disciplinary translation and trigger imagination among graduate students with established expertise requires further investigation. Furthermore, Kurebayashi (2024) theoretically highlighted that practical inquiry activities alone are insufficient; rather, providing linguistic scaffolding regarding cross-disciplinary connections and socio-historical contexts during "reflection time" is vital for fostering metacognition [9].

B. Research Participants

The participants are graduate students majoring in transdisciplinary fields at Kanazawa University. Although this is a unique group situated at the intersection of established expertise and the growing trend toward interdisciplinary integration, exposure to a STEAM education framework focused on ART holds promise for fostering interdisciplinary development within their own fields of expertise. However, since short-term interventions such as those in this study are unlikely to lead to actual behavioral change, this paper focuses on the internal processes through which graduate students—who are in the process of establishing their expertise—interpret, accept, and assign meaning to art within an academic context.

C. Research Questions

As mentioned earlier, in this study, the aim is to qualitatively describe the process of participants' reception, interpretation, and meaning-making based on the following research questions. What cognitive and emotional responses (such as a shift in existing perceptions, confusion, or the understanding and concerns regarding background knowledge gained through explanations) do graduate students in non-art fields exhibit through multimodal art appreciation activities involving artworks that express the STEAM concept in an explanatory and meta-level manner (RQ1)? How do they interpret the artworks and STEAM education (and the role of art within it), and how do they perceive these in relation to their own expertise and career paths (RQ2)?

II. Theoretical Framework

To establish a theoretical foundation for designing and analyzing the STEAM art appreciation practice, this study integrates three interconnected perspectives: (1) mutually instrumental relations as the overarching pedagogical ideal, (2) boundary objects and multimodal narratives as the mediating mechanism, and (3) multiple entry points and linguistic scaffolding as the means of cognitive access. First, regarding the pedagogical ideal, Mejias et al. (2021) critiqued conventional "one-sided instrumentalism" in STEAM education, wherein Art is relegated solely to an efficient pedagogical instrument or visual decoration for learning STEM content, thereby compromising its intrinsic critical perspective and subjective expressive exploration [6]. Conversely, they advocated for a "mutually instrumental and pedagogical relationship," a state in which STEM and Art interact symmetrically on an equal footing (co-equal partnership) to drive reciprocal learning, share epistemic practices, and deepen conceptual understanding across both domains [6].

Second, to realize such cross-disciplinary interaction, learning must occur at the intersection of different cultural practices. Vartiainen (2025) highlights the role of "boundary objects"—specifically imagination and imaginative practices—in bridging learners' everyday cultural practices with the epistemic practices of STEAM [8]. A boundary object establishes communication between disparate worlds and creates a common problem space while preserving the uniqueness of the intersecting domains [8]. Complementing this view, multimodal learning [7] facilitates conceptual comprehension by crossing and synthesizing visual, linguistic, and somatic modes. Introducing narratives and metaphors rooted in everyday experiences mitigates cognitive anxiety and enhances familiarity with complex scientific phenomena [7], [10]. Furthermore, whereas conventional STEM education emphasizes "convergent thinking" toward a singular optimal solution, the Art component sparks "multifaceted divergent thinking" [7], [11], encouraging learners to re-examine problems from broad perspectives and generate diverse meanings that complement scientific inquiry [12]. In this study, we extend this framework to higher education, positioning the exhibited multimodal artworks—equipped with fictional characters, historical metaphors, and layered meanings—not merely as visual aids, but as boundary objects intended to trigger learners' imagination and bridge their specialized academic backgrounds with unfamiliar scientific and everyday contexts [8].

Third, regarding how learners access these boundary objects, Gardner's Multiple Intelligences (MI) theory posits that individuals possess distinct cognitive profiles and thus engage with new material through different pathways, or "entry points": (1) Narrational, (2) Logical-Quantitative, (3) Experiential, (4) Foundational/Philosophical, and (5) Esthetic [13]. Art can serve as a multimodal medium that embeds these multiple entry points within a single exhibition space, theoretically allowing graduate students from varied academic disciplines to autonomously initiate inquiry through pathways most accessible to them. However, for non-art majors accustomed to structured logical reasoning, visual presentation alone may leave the underlying interdisciplinary connections opaque. As Kurebayashi (2024) pointed out, providing explicit "linguistic scaffolding" regarding cross-disciplinary connections and socio-historical contexts during reflection is vital for fostering metacognitive understanding [9], [14]. At the same time, such explicit linguistic framing carries a pedagogical tension: while it promotes convergent comprehension of the creator's intent, it may inadvertently constrain the autonomous divergent thinking that Art is meant to inspire.

The theoretical concepts outlined above are not intended to demonstrate complete educational effectiveness in this study; rather, they serve as the "theoretical foundation (intended hypotheses)" upon which the creators based the design of this exhibition and the gallery talks. At the same time, this study employs these theoretical intentions as an analytical framework to examine the extent to which they are accepted by actual learners, as well as where limitations or side effects may arise. Specifically, in the analysis, (1) descriptions that use fictional elements or metaphors within the works to lower psychological barriers to unknown scientific domains or to connect them to everyday life or one's own professional

context are treated as the function of "boundary objects"; (2) descriptions regarding the aesthetic appeal, narrative elements, and logical structures—the diverse angles that initially piqued each individual's interest—as reactions to "entry points"; and (3) we identified and interpreted free association (narrative generation) that is not bound by a single correct answer, as well as concerns about thoughts being constrained to specific interpretations by explanations or visual images, as divergent and convergent thinking, respectively. Mutually instrumental relations (the first perspective above) informed the design of the exhibition and the gallery talk as a pedagogical ideal, but were not used as an analytical category in this study.

III. Practice Design

A. Gallery Overview

The "Art in Life" gallery, curated by co-author Imakado and established at Kanazawa University's Natural Science Main Building in November 2025, hosted an exhibition themed "Stars and the Universe." Designed to connect STEM with everyday life through Art, its educational design rests on two pillars: (1) symmetrical STEAM integration positioning Art as an equal mediator (mutually instrumental) [6], and (2) multiple entry point architecture tailored to diverse cognitive styles [13]. All of the exhibited artworks feature "Kyukon-kun," an original character created by the artist, which guides the audience and sometimes poses questions to them (see Table I). Table I also outlines representative artworks, motifs, metaphors, and corresponding entry points.

B. Activities Design

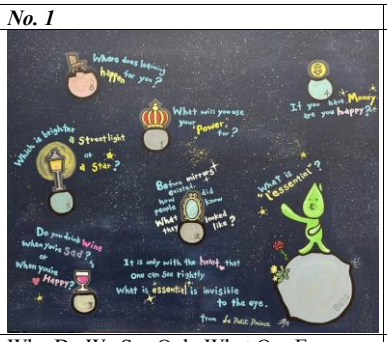
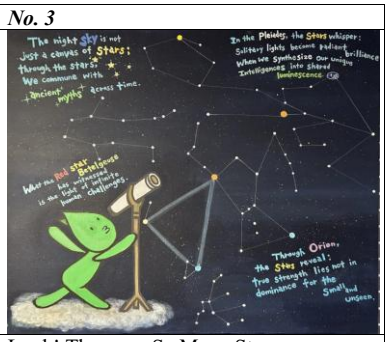
The appreciation activities in this study included commentary by the artist and were structured in two stages: free appreciation prior to the commentary, and a second appreciation based on the commentary. The purpose of this design is not to compare the effects of appreciation with or without commentary. Rather, by intentionally distinguishing between "free, intuitive appreciation" and "contextual, dialogic appreciation" (in which the artwork is reexamined in light of the artist's intentions and background knowledge), the study aims to describe the continuous internal process through which graduate students—who are establishing their expertise—interpret, accept, and assign meaning to art over the course of the entire session.

C. Commentary by the Artist

Participants listened to an approximately 10-minute oral explanation by Ariga, the artist of the artworks in the gallery and one of the co-authors. During the talk, she clarified that the gallery was explicitly designed to demonstrate the role of "Art" in STEAM education. Using specific artworks, she explicated the scientific and historical contexts embedded in familiar motifs. For instance, she explained how the "Miura-fold" (a traditional origami technique) is utilized in the deployable solar panels of space satellites and parallels the folding mechanisms of insect wings. Furthermore, she bridged everyday life and the history of space exploration by discussing the origins of "Apollo Chocolate," aiming to show how art serves as an accessible medium to spark awareness of the interconnectedness of various fields. These explanations are summarized in TABLE II. Following the talk, participants re-examined the exhibition and completed the post-intervention questionnaire. For more detailed research methods, please refer to the next chapter.

The authors acknowledge that some researchers were involved in the design and organization of the exhibition, and one author was also the artist of all exhibited artworks. This positionality may have influenced the interpretation and categorization of participants' responses. The findings should therefore be understood as exploratory interpretations rather than fully independent assessments.

TABLE I. List of Artworks in the Gallery (Partial)

	No. 1	***No. 2***	***No. 3***
Works			
Title	Why Do We See Only What Our Eyes Can See?	The Sky is the Limit!	Look! There are So Many Stars.
Motifs and Elements	"The Little Prince" (B612), Philosophical Questions, Six Planets (Crown, Mirror, Wine, etc.)	The Wright Brothers, Bicycles, and Airplanes	Starry Sky, Intentionally Altered Star Colors and Temperatures
Message and Metaphor	Awareness of "important yet invisible things," such as the essence of things, the structure of systems, and hard work	"From Seed to Sky": A Metaphor for Crossing Boundaries and Growth Between Everyday Life (Bicycles) and Science (Airplanes)	Proactively generate and explore questions like "why colors are different?"
Corresponding Entry Points	Esthetic, Foundational and Narrational	Esthetic, Foundational and Experiential	Esthetic and Experiential

	No. 4	*No. 5*
Works		
Title	The World of 100 km High	Journey to Space: The Miura Fold Edition
Motifs and Elements	Apollo 11, Apollo Chocolate (launched in 1969), Japan's Osumi satellite	Miura fold (origami technique), solar panels on satellites, butterfly wings
Message and Metaphor	Bridging the gap between space research and everyday life (sweets) and making the history of science more accessible	The Coexistence of a Single Sheet of Origami (Low-Tech) and Cutting-Edge Space Science (High-Tech) with the Structures Found in Nature
Corresponding Entry Points	Esthetic, Logical-Quantitative and Experiential	Esthetic and Logical-Quantitative

TABLE II. STRUCTURE OF THE ARTIST'S COMMENTARY

Types	***Main Topic***	***Examples of Commentary***
Scientific and Historical Contexts of the Artworks	Aerospace engineering and origami (Biomimicry)	"The 'Miura fold,' which is used for deploying solar panels on satellites, shares a structural similarity with the way insects fold their wings."
	The history of space development and everyday life	"Where does the sky end and space begin?" "We ourselves are aliens." "Apollo Chocolate was created in the year Apollo 11 landed on the moon, and its shape is modeled after the spacecraft."
	The temperature of stars and literary metaphors	"Stars come in various colors depending on their temperature." "Each of the six planets that appear in The Little Prince has its own significance."
	Technological advancements and interdisciplinary approaches	"Before building an airplane, the Wright brothers ran a bicycle shop (how a single event can lead to a completely different field)."
The Role of Art in STEAM	Diverse entry points	"Viewing the artwork sparks interest and engagement through 'entry points'—such as English, space, or the number of planets—that vary from person to person."
	Awareness through visual imagery and the reduction of psychological barriers	"Rather than reading text, when you see a visual image (art), the information comes in all at once, and it serves as a medium that helps you realize, 'Oh, is that so?'"
	Connecting meaning through imagination (Narrative acceptance)	"Since it's a metaphor, it requires imagination, but you're free to interpret it as you like and assign various meanings to it." "Imagination is the ability to connect your own areas of expertise with the subject at hand."
	The expansion of diverse approaches	"By transforming a work into lyrics or dance and connecting it to physical expression—that is, by converting it into a different form of expression—new perspectives and discoveries emerge."

IV. RESEARCH METHODS

A. Data Collection

Ten graduate students (master's program, Graduate School of Frontier Science Initiative, Kanazawa University) enrolled in the 2026 course "STEAM Education and Creativity" participated. Academic specializations span information technology, regional policy, tourism science, urban planning, organizational psychology, and civil/environmental engineering. Participants' backgrounds in art (e.g., prior art education or practice) were not collected. Accordingly, "non-art major" in this study refers to participants' graduate-level fields of specialization and does not necessarily mean that they had no experience with art. The course content significantly overlapped with the research theme. Participants' prior learning experiences and knowledge of STEAM were not systematically measured, so the possible influence of the course content and of participants' prior interest in STEAM on their responses cannot be ruled out (see Limitations). The ethical considerations of this study were approved by the Ethics Committee for Human Research of the Institute of Transdisciplinary Sciences at Kanazawa University[1]. The study's purpose and the academic use of the data were explained to all participants, and written informed consent was obtained. Anonymity was strictly maintained, and participation had no bearing on academic grading. Also, we instructed them to candidly express any negative questions or concerns they had about the artworks or the commentary. The study was conducted between June 18 and July 2, 2026. All practices such as appreciations, gallery talks, and data collection procedures were conducted in Japanese. The online open-ended questionnaire (also in Japanese) consisted of the following prompts across both phases: Q1-1 asked, "Please describe what you felt and thought through the autonomous appreciation of the artworks."; Q1-2 asked, "Please describe what you felt and thought through the appreciation of the artworks and the artist's commentary." These two prompts were not identical. While Q1-1 asked participants to describe their thoughts and feelings through independent appreciation of the exhibition, Q1-2 explicitly referred to both the artworks and the artist's commentary. Therefore, differences between

[1] Approval No. is "融 R8-021".

the two responses cannot be attributed solely to the artist's intervention. Prompt wording, repeated exposure to the artworks, and the timing of the second response may also have influenced participants' descriptions. Q2-1/Q2-2 asked, "Based on this experience, what do you think STEAM is?". Q1-1 and Q2-1 were asked after the first appreciation without commentary; Q1-2 and Q2-2 were asked after the second appreciation, which followed the commentary. Open-ended survey responses (mean: 175.4 characters, SD = 102.3 per person, in Japanese) were collected. To preserve the subtle linguistic and cultural nuances of the participants' expressions, the entire qualitative analysis was performed directly on the original Japanese transcripts.

B. SCAT Analysis

The responses were segmented and analyzed using Steps for Coding and Theorization (SCAT) [15], combined with Fukushi and Nago's strip-segmentation technique [16] for short-text optimization. While the original SCAT method is typically applied to individual narratives, this study utilized the strip-segmentation approach to divide all participants' responses into meaningful text segments. We then applied the SCAT coding steps across all segments to integrate the extracted concepts into cross-sectional major and subcategories. The aim of this approach was to describe and structure the participants' interpretations, perceptions, and attributions of meaning based on a small amount of text data. After dividing the data into meaningful units, a total of 92 segments were extracted: 52 segments for Q1 (first round: 31, second round: 21) and 40 segments for Q2 (first round: 22, second round: 18). Because the segmentation was iteratively revised during the process of key phrase extraction and categorization, the numbering of some segments (e.g., Segments 91 and 92 in Appendix II) is non-sequential. Furthermore, in the analysis of the second round of responses, there were 20 segments that explicitly included the content of the artist's commentary summarized in Table II (13 out of 21 segments [62%] in Q1, and 7 out of 18 segments [39%] in Q2). The number of segments was not evenly distributed across participants: Participants A and J each contributed 15 segments (16% of the 92 segments each), whereas the other participants contributed 4 to 11 segments each. The number of segments in a category therefore does not indicate how many participants expressed the corresponding view; the number of participants is shown as (n/10) in Section V. The criterion for judging a 'repeat' was whether the participant's response explicitly included the content of the artist's commentary. Recent findings by Onuki and Nakamura (2026) regarding qualitative analysis, including SCAT, demonstrated the efficacy of Large Language Models (LLMs) in formal concept extraction, while also highlighting the need for human analysts for context-aware interpretation [17]. LLMs were used only supplementarily (for drafting paraphrases of key phrases, suggesting candidate category names, and checking structural coherence), and their use was not systematically recorded[2](see the footnote for the services used and the types of data entered). To control for potential analytical bias and prevent over-theorization, we clearly separated the subjective design intentions (Tables I and II) from the learners' actual written responses, and the authors manually cross-checked all data to finalize all category definitions. The conceptual framework was organized into major and subcategories and described as the results. Only the Results presented in Section V and the representative quotations selected for this manuscript were translated into English. In this study, the narrative description of the categories in Section V corresponds to the SCAT storyline. To ensure the accuracy of the translations and to confirm that the original psychological and contextual meanings were maintained, a back-translation procedure was conducted.

TABLE III. REPRESENTATIVE EXAMPLES OF THE SCAT CODING

Segments No.	***(1) Text***	***(2) Key Phrases***	***(2)-(3) Sub-category (Contextual Concepts)***	***(4) Major Category (Themes/Constructs)***
12 (Q1-1)	...I can express what I like, and even if I dislike something, expressing it through art hurts no one...	- Express what I like - Expressing through art hurts no one	⟨Reframing art from technical apprehension into a medium for free self-expression⟩	[Destabilization of Pre-existing Perceptions of Art and Recognition of Underlying Messages]
13 (Q1-1)	I am not good at drawing, but considering it as expressing myself, it is free and easy to express.	- Not good at drawing - Expressing myself - Free and easy to express		
14 (Q1-1)	Even though "Kyukon-kun" is not a real character, I was curious about the meaning behind the illustration and where it came from.	- not a real character - the meaning behind - where did it come from	⟨Ambiguity and confusion regarding artwork intent and messaging prior to commentary⟩	[Perplexity in Artwork Appreciation and Concerns Over the Fixation of Interpretation]
40 (Q1-2)	Having commentary instantly increased the resolution and deepened my understanding... but situations where the explanation panel stands out more than the artwork, shaking the interpretation of the work, must be avoided...	- Commentary instantly increased resolution and deepened understanding - Situations where the explanation panel stands out, shaking the interpretation, must be avoided	⟨ Concerns that visual images and commentary might fixate or guide interpretation ⟩	
65 (Q2-1)	Talking to teachers... implementing STEAM education... it does not yield immediate effects... I think it is a very difficult challenge.	- Current workplace or field - Doesn't yield immediate effects - Very difficult	⟨Points regarding pedagogical challenges in classroom implementation and evaluating learning outcomes⟩	[Identification of Conceptual Difficulties and Practical Challenges Due to the Vastness of STEAM Education]
79 (Q2-2)	I think STEAM is a concept that should be actively introduced from elementary education. On the other hand, I also think it is difficult to measure its outcomes.	- Actively introduced from elementary education - Difficult to measure its outcomes		

[2] For this process, we supplementarily used the web-based Gemini service (Gemini 3.1 Pro, 3.8 Flash, and 4 Argon models). All interactions were conducted under privacy settings ensuring that user inputs were not used for model training. While partial response texts, key phrases during the refinement process, and category names were input into the models, the full raw dataset or personal information was never transmitted externally.

V. Results

A. Reception and Interpretation of Artworks

The complete categorization of the 52 segments for Q1 is shown in Appendix I. To clarify the distribution of responses and avoid overgeneralizing the findings, the number of participants who expressed opinions corresponding to each major category or subcategory is indicated in parentheses as (n/10) throughout the text.

During the initial appreciation before receiving the commentary, the participants first demonstrated [Intuitive and Affective Reception and Psychological Proximity] (6/10). Taking their ⟨Intuitive and affective appreciation and evaluation of form and scale⟩ (4/10) of the artworks as a starting point, two participants (F and J) described a ⟨Reduction of psychological distance to science (the universe) through approachable expressions⟩ (2/10), which they associated with warm elements such as characters and origami. Participant J also expressed this reaction in the second response following the commentary. Furthermore, Participant G felt a sense of familiarity, as indicated by a ⟨Reference to affinity with artworks through the projection of personal experiences and research fields⟩ (1/10). At the same time, even during the first appreciation stage, the participants were already experiencing a [Destabilization of Pre-existing Perceptions of Art and Recognition of Underlying Messages] (8/10). Despite feeling self-conscious about their drawing skills, two participants (A and E) showed a ⟨Reframing art from technical apprehension into a medium for free self-expression⟩ (2/10). In addition, three participants (H, I, and J) showed a ⟨Renewed recognition of art as a positive expression beyond conventional genres or satire stereotypes⟩ (3/10). Participant J stated, "I sensed a common message of moving forward positively and valuing connections between people." However, while there was a ⟨Recognition of messages from the combination of visual expressions and captions⟩ (3/10), there were also cases where participants were unable to independently decipher the purpose of the characters or the intent behind the questions posed in the artworks, leading to ⟨Ambiguity and confusion regarding artwork intent and messaging prior to commentary⟩ (2/10). For instance, Participant E noted that even though "Kyukon-kun" (the original character appearing in all the exhibited artworks; see Section III.A) is not a real character, they were curious about the meaning behind the illustration. Participant B showed an ⟨Interest in the presence of the artist⟩ (1/10).

During the second appreciation, which included the commentary from the artist, participants' descriptions shifted toward [Understanding Artwork Contexts Through Explanatory Commentary and Connecting Science to Daily Life] (7/10). Many participants (9/10) directly quoted or repeated words from the commentary as clues. However, as the prompt for this phase (Q1-2) explicitly directed participants to reflect on the artist's commentary, this repetition may have been partially guided by the wording of the question itself, rather than being a purely spontaneous reliance. Nonetheless, responses in this phase more often described a ⟨Facilitation of comprehension and rational interpretation through explanatory commentary⟩ (4/10). By engaging with specific examples such as "Apollo Chocolate" and the "Miura fold," they expressed a sense of conviction, demonstrating a ⟨Recognition of connections between science and daily life through concrete everyday examples⟩ (4/10). Participant A wrote, "What interested me most was that Apollo Chocolate was created to commemorate the Apollo 11 moon landing. After hearing this story, I felt that Apollo Chocolate does indeed look like a rocket." Similarly, participants showed [Appreciation and Reception of Art's Function as an "Entry Point"] (4/10). They demonstrated an ⟨Understanding and acceptance of art's function as an entry point for eliciting diverse interests⟩ (3/10), acknowledging that the wealth of information embedded in the artworks, including the conceptual explanations, serves to spark varied curiosities. Additionally, Participant F demonstrated a ⟨Recognition of enhanced accessibility for non-experts through visual representation⟩ (1/10).

Participants did not merely show understanding or acceptance of the explanatory content; there were also reactions involving [Free Association and Interpretation of Artworks, with Attention to Exhibition Methods and Spatial Design] (4/10). Through the appreciation process, participants engaged in ⟨Spontaneous association and narrative generation based on artwork motifs⟩ (2/10), such as imagining the characters drawn on the grid living inside a house. Additionally, there were instances of ⟨Re-observation of artworks and verbalization of personal reflections prompted by commentary⟩ (1/10), and they demonstrated an ⟨Objective attention to spatial presentation and communicability to external audiences⟩ (2/10), noting the exhibition methods and how the displays and explanations were directed toward children. On the other hand, critical perspectives regarding visual imagery and verbal explanations were also expressed as [Perplexity in Artwork Appreciation and Concerns Over the Fixation of Interpretation] (4/10). Specifically, there were ⟨Concerns that visual images and commentary might fixate or guide interpretation⟩ (2/10). Participant D pointed out that while explanatory panels deepen understanding, if they are too conspicuous, they might lead to a situation that "undermines the interpretation of the artwork." Similarly, Participant F noted that while art broadens one's thinking, "creativity may become bound by constructed images... making it difficult for one's consciousness to turn toward what lies outside of art."

B. Perceptions of STEAM Education and the Role of Art

The categorization of the 40 segments extracted for Q2 is shown in Appendix II. Through the appreciation process, participants initially structured STEAM education as a [Recognition of Breaking Existing Frameworks and Acquiring Multifaceted Perspectives Through the Integration of Diverse Knowledge] (phase 1: 6/10; phase 2: 4/10). STEAM was not merely viewed as the juxtaposition of multiple academic disciplines, but rather as a ⟨Perception of multifaceted viewpoints for generating novel ideas from phenomena⟩ (2/10) and as a ⟨Recognition of transdisciplinary knowledge integration and breaking existing frameworks⟩ (6/10) that connects specialized fields of science and technology. Furthermore, this cross-disciplinary perspective led to a [Recognition as a Pragmatic Approach to Resolving Everyday Inquiries and Complex Real-World Challenges] (phase 1: 3/10; phase 2: 3/10). Participants positioned STEAM as a ⟨Perception of experiential learning through observation and making, originating from everyday inquiries⟩ (2/10), and viewed it as indispensable, showing a ⟨Recognition of applicability toward addressing complex societal challenges⟩ (2/10). They pointed out that implementing this requires a ⟨Recognition of the necessity of interdisciplinary collaboration for sharing cross-disciplinary

knowledge⟩ (1/10). Additionally, Participant A showed an ⟨Association with personal future career development and trajectory⟩ (1/10), linking STEAM to their own professional expertise and future role of engaging in social issue resolution as a working professional in their own field starting next year. However, only Participant A linked STEAM to their own future career; thus, the present data provide limited insight into how participants related STEAM to their own expertise and career paths.

Regarding the role of Art in STEAM, [Understanding and Empathy for Art's Role as an "Entry Point" for Diverse Interests and as a Medium for Self-Expression and Communication] (phase 1: 5/10; phase 2: 5/10) was demonstrated. In addition to the ⟨Articulation of the function of art as an "entry point" for intellectual curiosity⟩ (2/10)—intended to mitigate aversions to science and mathematics—a ⟨Recognition of the potential for effective information transmission and self-expression through visual and non-verbal representation⟩ (3/10) was also observed. Participant I provided insight into the bidirectional relationship between engineering and art, noting that engineering designed to reduce air resistance (such as the streamlined shape of a car) leads to beautiful design. The inclusion of art was positively evaluated as fostering a ⟨Recognition of allowing diverse interpretations without singular correct answers, respecting individuality, and expanding human potential⟩ (4/10). However, while participants resonated deeply with the ideological values of STEAM, they also provided descriptions related to the [Identification of Conceptual Difficulties and Practical Challenges Due to the Vastness of STEAM Education] (phase 1: 2/10; phase 2: 2/10). A ⟨Cognitive difficulty in grasping the overarching framework of integrated domains and perceived alienation from art⟩ (2/10) persisted throughout the activities; for instance, early in the session, Participant G expressed confusion over "What constitutes having learned art?", and later in the process, Participant B similarly noted the difficulty in grasping the concept. Furthermore, ⟨Points regarding pedagogical challenges in classroom implementation and evaluating learning outcomes⟩ (2/10) were also raised. Comparing the two phases, the number of participants whose descriptions corresponded to the integration of diverse knowledge and the breaking of existing frameworks decreased slightly from six to four, and three of the four second-phase participants (A, C, and J) explicitly included content from the artist's commentary. Regarding the role of Art, the number of participants who described Art as allowing diverse interpretations without a singular correct answer increased from two (H and J) to four (D, E, H, and J). However, two of these four second-phase responses (E and J) explicitly included the artist's commentary, which stated that viewers were free to interpret the metaphors as they liked. These differences may therefore reflect the incorporation of the commentary rather than independent changes in participants' views.

VI. Discussion

A. *Aspects of the Reception of Art as Boundary Objects and Entry Points*

As shown in Section V.A., during the free appreciation stage prior to the commentary, some participants (F and J) described feeling closer to unfamiliar scientific elements through approachable expressions such as characters and origami. Vartiainen (2025) theoretically positioned "imagination"—such as stories and fictional elements—as boundary objects that bridge everyday practices and STEAM [8]. The process observed in this study suggests that even for learners who are already in the process of establishing their respective fields of expertise, the fictional nature of the artworks has the potential to mitigate cognitive barriers to unfamiliar domains. Furthermore, some participants described the provision of diverse entry points through free expression as a role of Art in STEAM. These descriptions may reflect participants' understanding of the artist's commentary or their own impressions of the exhibition, and the present analysis does not distinguish between the two. Nor do they demonstrate whether the exhibited artworks actually served as entry points to the exhibition's theme, "Stars and the Universe." Nevertheless, some participants described a ⟨Reduction of psychological distance to science (the universe) through approachable expressions⟩ (2/10) and a ⟨Recognition of messages from the combination of visual expressions and captions⟩ (3/10).

B. *Incorporation of the Artist's Commentary and Its Relation to Interpretive Openness*

As mentioned earlier, the responses following the second appreciation contained segments that directly quoted or restated the content of the artist's commentary (13 of 21 segments for Q1 and 7 of 18 segments for Q2). Because Q1-2 explicitly referred to the artist's commentary, and because the two prompts were not identical, this incorporation cannot be interpreted simply as participants' dependence on the explanations. Several interpretations remain possible: participants may have followed the wording of the prompt, may have used the explanations to make sense of the artworks, or may have reproduced what they had just heard as a short-term memory or a superficial impression. In the first appreciation, some participants (E and I) described confusion about the intent of the artworks; however, the present data do not show whether the incorporation of the commentary in the second response was a response to that confusion. Kurebayashi (2024) emphasized the importance of providing linguistic scaffolding regarding interdisciplinary connections and socio-historical contexts during reflection [9]. Meanwhile, some participants (2/10; D and F) expressed concerns that visual representations and explanatory panels might guide or constrain individual interpretations. These observations suggest a potential tension between providing interpretive guidance and preserving openness in art appreciation. However, the present data do not establish that verbal explanations directly restricted participants' divergent thinking. Furthermore, the artist explicitly stated during the commentary, "Since it's a metaphor, (…) you're free to interpret it as you like and assign various meanings to it." Therefore, further investigation is needed to explore how to balance the provision of linguistic scaffolding with the preservation of autonomous divergent thinking.

C. *Limitations*

This study has several limitations. First, participants were recruited from a course entitled 'STEAM Education and Creativity.' Because the participants were enrolled in a course whose theme overlapped with this study, the influence of the course content on their responses could not be separated from the effect of the appreciation and commentary, and also our study does not aim to prove causal relationships using a control group. In addition, participants' motivations for enrolling and their prior interest in STEAM were not systematically measured, so self-selection bias cannot be ruled

out. Participants' prior experience with art was also not collected, so its influence on their responses could not be examined. As stated at the outset, the objective is to gain a more detailed understanding of the process by which graduate students—who are establishing their expertise—interpret, accept, and attribute meaning to art within an academic context. Therefore, the structured interpretations, reception patterns, and suggested tendencies identified in this study need to be verified as generalizable theories in future research through quantitative analyses with larger sample sizes and causal relationship analyses. Second, as mentioned earlier, some of the authors of this study were involved in the curation and organization of this gallery, and one of the authors was the artist of all the works on display. This positionality may have influenced the interpretation and categorization of participants' responses. To address this, a co-author not involved in the design (Shimogohri) conducted a partial validation of the analytical results. Nevertheless, the findings should be understood as exploratory interpretations rather than fully independent assessments. Third, the non-equivalence of the two prompts limits direct comparisons between pre-commentary and post-commentary responses. In particular, the explicit reference to the artist's commentary in Q1-2 may have encouraged participants to incorporate the artist's explanations into their responses. While this incorporation of the commentary can be interpreted as an indication that participants understood and accepted the explanations, it is also possible that these responses were based merely on short-term memory or superficial impressions. In addition, because the number of segments differed across participants (e.g., 15 segments each for A and J), the number of segments in a category should not be interpreted as the prevalence of that view among the ten participants. Finally, because the criteria for judging 'repeated' segments were explicitly based on the inclusion of the artist's commentary and were thus exclusively applied to the post-commentary responses, there is a methodological asymmetry in the analysis between the two phases. Thus, demonstrating long-term conceptual transformation requires further practical activities (such as ongoing workshops) and quantitative verification with larger sample sizes.

VII. Conclusion

In this study, we exploratively described the internal processes by which ten non-art-major graduate students interpreted and attributed meaning to artworks expressing the STEAM concept. Through autonomous appreciation and subsequent artist commentary, the participants' responses were analyzed using the SCAT method.

The findings revealed the following. First, regarding cognitive and emotional reactions (RQ1), in the initial free appreciation, some participants' descriptions suggested that familiar imaginative elements, such as characters and origami, made unfamiliar scientific fields feel closer. Some participants also described reframing their pre-existing perceptions of art as a medium for free self-expression, though abstract motifs caused initial confusion. In the second phase, following the artist's commentary, participants frequently incorporated the provided scientific and historical contexts into their descriptions. However, because the second prompt explicitly directed attention to the commentary, differences between the two stages limit direct comparisons. Furthermore, some participants raised concerns that explanatory panels and constructed imagery might guide their interpretations, highlighting a potential tension between providing interpretive guidance and preserving openness in art appreciation.

Second, regarding perceptions of STEAM and the role of Art (RQ2), some participants recognized STEAM as a practical approach to breaking down existing frameworks through interdisciplinary knowledge integration. Some participants also positively evaluated Art as an entry point for intellectual curiosity and a non-verbal medium for communication. Conversely, cognitive challenges in grasping the vastness of the STEAM framework and practical pedagogical difficulties were raised by four participants across both phases. Regarding the relationship with their own expertise and career paths, although some participants utilized their disciplinary backgrounds for interpretation, explicit connections to future career development were scarce, indicating a limitation of this short-term intervention.

Overall, these exploratory results provide insights into how multimodal meta-artworks may serve as boundary objects to initiate reflection on STEAM among non-art majors. However, educators must carefully balance the provision of linguistic scaffolding with the preservation of autonomous interpretations. Future research should incorporate interactive workshop designs to facilitate a transition from conceptual understanding to active value generation, supported by quantitative verification with larger sample sizes to build upon these initial findings.

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APPENDIX I. LIST OF EXTRACTED MAJOR CATEGORIES AND SUBCATEGORIES (Q1)

Major Category (Themes/Constructs)	*Sub-category (Contextual Concepts)*	*Segment No.*	*Response Phase*	*Participants*	*Repeat?*
[Intuitive and Affective Reception and Psychological Proximity]	⟨Intuitive and affective appreciation and evaluation of form and scale⟩	1	1	A	
		2			
		6	1	B	
		7	1	C	
		21	1	G	
	⟨Reduction of psychological distance to science (the universe) through approachable expressions⟩	16	1	F	
		28	1	J	
		29			
		50	2		○
		51			
	⟨Reference to affinity with artworks through the projection of personal experiences and research fields⟩	19	1	G	
		20			
		22			
[Destabilization of Pre-existing Perceptions of Art and Recognition of Underlying Messages]	⟨Reframing art from technical apprehension into a medium for free self-expression⟩	3	1	A	
		12	1	E	
		13			
	⟨Renewed recognition of art as a positive expression beyond conventional genres or satire stereotypes⟩	23	1	H	
		24	1	I	
		30	1	J	
		31			
	⟨Interest in the presence of the artist⟩	5	1	B	
	⟨Recognition of messages from the combination of visual expressions and captions⟩	8	1	D	
		17	1	F	
		25	1	I	
		26			
[Understanding Artwork Contexts Through Explanatory Commentary and Connecting Science to Daily Life]	⟨Facilitation of comprehension and rational interpretation through explanatory commentary⟩	32	2	A	○
		35			
		36	2	B	○
		38	2	D	○
		47	2	I	○
		48			
	⟨Recognition of connections between science and daily life through concrete everyday examples⟩	34	2	A	○
		45	2	G	○
		46	2	H	○
		49	2	J	○
		52			
[Appreciation and Reception of Art's Function as an "Entry Point"]	⟨Understanding and acceptance of art's function as an entry point for eliciting diverse interests⟩	33	2	A	○
		37	2	C	○
		39	2	D	○
	⟨Recognition of enhanced accessibility for non-experts through visual representation⟩	43	2	F	○
[Free Association and Interpretation of Artworks, with Attention to Exhibition Methods and Spatial Design]	⟨Spontaneous association and narrative generation based on artwork motifs⟩	4	1	A	
		15	1	E	
	⟨Re-observation of artworks and verbalization of personal reflections prompted by commentary⟩	41	2	E	
		42			

	⟨Objective attention to spatial presentation and communicability to external audiences⟩	9	1	D	
		10			
		11			
		18	1	F	
[Perplexity in Artwork Appreciation and Concerns Over the Fixation of Interpretation]	⟨Ambiguity and confusion regarding artwork intent and messaging prior to commentary⟩	14	1	E	
		27	1	I	
	⟨Concerns that visual images and commentary might fixate or guide interpretation⟩	40	2	D	
		44	2	F	

APPENDIX II. LIST OF EXTRACTED MAJOR CATEGORIES AND SUBCATEGORIES (Q2)

Major Category (Themes/Constructs)	***Sub-category (Contextual Concepts)***	***Segment No.***	***Response Phase***	***Participants***	***Repeat?***
[Recognition of Breaking Existing Frameworks and Acquiring Multifaceted Perspectives Through the Integration of Diverse Knowledge]	⟨Perception of multifaceted viewpoints for generating novel ideas from phenomena⟩	57	1	C	
		92	2	A	
		78	2	C	◯
	⟨Recognition of transdisciplinary knowledge integration and breaking existing frameworks⟩	53	1	A	
		56	1	B	
		61	1	F	
		62	1	F	
		69	1	I	
		71	1	J	
		91	2	A	◯
		84	2	G	
		88	2	J	◯
[Recognition as a Pragmatic Approach to Resolving Everyday Inquiries and Complex Real-World Challenges]	⟨Perception of experiential learning through observation and making, originating from everyday inquiries⟩	68	1	I	
		72	1	J	
		89	2		
	⟨Recognition of applicability toward addressing complex societal challenges⟩	54	1	A	
		75	2		◯
		83	2	F	◯
	⟨Association with personal future career development and trajectory⟩	76	2	A	
	⟨Recognition of the necessity of interdisciplinary collaboration for sharing cross-disciplinary knowledge⟩	55	1	A	
[Identification of Conceptual Difficulties and Practical Challenges Due to the Vastness of STEAM Education]	⟨Points regarding pedagogical challenges in classroom implementation and evaluating learning outcomes⟩	65	1	H	
		79	2	D	
	⟨Cognitive difficulty in grasping the overarching framework of integrated domains and perceived alienation from art⟩	63	1	G	
		64			
		77	2	B	
[Understanding and Empathy for Art's Role as an "Entry Point" for Diverse Interests and as a Medium for Self-Expression and Communication]	⟨Recognition of the potential for effective information transmission and self-expression through visual and non-verbal representation⟩	59	1	E	
		60	1		
		73	1	J	
		86	2	I	
		87			
	⟨Articulation of the function of art as an "entry point" for intellectual curiosity⟩	58	1	D	
		70	1	I	
		80	2	D	
	⟨Recognition of allowing diverse interpretations without singular correct answers, respecting individuality, and expanding human potential⟩	66	1	H	
		67			
		74	1	J	
		81	2	D	
		82	2	E	◯
		85	2	H	
		90	2	J	◯