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Reconstructing art with mathematical functions: A qualitative case study integrating mathematics and art through GeoGebra

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Abstract

The increasing use of digital technologies in arts education has created new opportunities to explore connections between mathematical representation, visual form, and creative practice. In this context, dynamic mathematics software such as GeoGebra provides a flexible environment for examining and reconstructing artistic compositions through mathematical and geometric representations. This qualitative case study examined how first-year students in an audiovisual arts program used GeoGebra to reconstruct selected compositions by Yiannis Moralis through mathematical functions and geometric objects. All 72 students enrolled in the course received compulsory introductory instruction in GeoGebra. The assessed semester assignment, which contributed 30% of the final course grade, offered 18 alternative topics; 14 students voluntarily selected Topic 18, the GeoGebra reconstruction task. The analyzed corpus comprised 12 reflective narratives and 12 accessible GeoGebra files, with both data sources available for 11 participants. Reflexive thematic analysis of the narratives was combined with structural and interpretive analysis of the digital constructions. Descriptive theme-presence counts and a case-by-case triangulation matrix were used to examine patterns across this topic-selected corpus. The artifact analysis identified substantial variation in modeling approaches, including dense use of domain-restricted linear and quadratic functions, hybrid combinations of functions and geometric objects, polygonal decomposition, and polynomial curve fitting. Students reported recurring difficulties with complex curves, parameter sensitivity, domain selection, vertical contours, and software use. Their affective accounts were mixed, encompassing curiosity, frustration, persistence, fatigue, incompleteness, and satisfaction. The findings indicate that the activity created opportunities for iterative representational experimentation and prompted some students to describe mathematics as an artistic medium. However, the data do not establish generalized learning gains or measured attitude change, and the findings are limited by the small, self-selected topic group and the graded instructional context.

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1. Introduction

Mathematics and art are often seen as belonging to distinct, even opposing domains of human cognition, with mathematics associated with abstraction, formalism, and logical rigor, while art is linked to creativity, expression, and subjective interpretation. This perceived dichotomy is especially evident in educational contexts, where students, especially those from humanities-oriented backgrounds, frequently experience mathematics as disconnected from their interests and modes of thinking. As a result, negative attitudes toward mathematics, low self-confidence, mathematical anxiety, and limited engagement are common challenges in introductory mathematics courses outside traditional Science, Technology, Engineering, and Mathematics (STEM) programs.^{1–4}

Despite this divide, the relationship between mathematics and art is historically and conceptually profound. Mathematical structures such as symmetry, proportion, curvature, geometric abstraction, and visual harmony have long informed artistic creation, while visual art has served as a medium through which mathematical ideas can be explored, represented, and communicated.^{5–7} Philosophical and educational perspectives have consistently emphasized mathematics as a creative and imaginative human endeavor, deeply connected to aesthetic judgment, intuition, and meaning-making rather than solely to formal symbolic manipulation.^{8–10} Recognizing and leveraging these connections in educational settings offers an opportunity to reconceptualize mathematics as a constructive, expressive, and culturally situated discipline.

Recent advances in digital technologies have further strengthened the potential for interdisciplinary approaches to mathematics education. Dynamic mathematics environments enable the real-time visualization and manipulation of mathematical objects, allowing learners to explore the relationship between algebraic representations and visual form interactively.^{11–13} Such environments support multiple representations, experimentation, and iterative refinement, which are central to conceptual understanding and sense-making in mathematics.¹⁴

Among these tools, GeoGebra occupies a distinctive position due to its integrated combination of dynamic geometry, algebra, and calculus within a single learning environment.¹⁵ By allowing learners to coordinate symbolic, graphical, and visual representations simultaneously, GeoGebra supports representational fluency and visual reasoning that are particularly valuable in interdisciplinary and creative learning contexts.^{15–18} A substantial body of research has documented the positive effects of GeoGebra on students' conceptual understanding, engagement, and motivation across a range of mathematical topics.^{15–17}

Within this broader landscape, the integration of mathematics and art through digital tools aligns closely with Science, Technology, Engineering, Arts, and Mathematics (STEAM)-oriented educational approaches, which seek to enrich STEM learning by incorporating artistic, creative, and humanistic perspectives.^{19–21} Interdisciplinary activities that combine mathematical modeling with artistic exploration have been shown to support not only cognitive learning outcomes, but also affective dimensions such as enjoyment, confidence, creativity, and a sense of ownership over learning.^{22–25} These affective dimensions are especially important for students who do not identify strongly with mathematics and who may otherwise disengage from mathematical content.^{26,27}

Research on affective learning further underscores the central role of emotions, attitudes, and motivation in shaping learning experiences. Theories of affective learning and optimal experience suggest that positive emotional states such as curiosity, immersion, and enjoyment can enhance persistence, creativity, and deep engagement with complex concepts.^{28–30} In mathematics education, affective factors have been identified as particularly influential for learners with prior negative experiences or low self-efficacy, reinforcing the need for learning environments that address emotional as well as cognitive dimensions of learning.^{4,31–33}

At the same time, recent surveys of empirical research in mathematical modeling and digital learning environments highlight an important imbalance in the literature.⁴ While quantitative studies have produced substantial evidence regarding performance-related outcomes, fewer studies have examined how learners experience mathematics in innovative, interdisciplinary settings, particularly from qualitative and interpretive perspectives.^{24,34} As a result, more situated, context-sensitive studies are needed that explore students' perceptions, emotional responses, and meaning-making processes when mathematics is embedded in creative and culturally meaningful activities.^{35–37}

To address this gap, the present study presents a small-scale qualitative case study that explores how foundational mathematical concepts can be experienced through artistic reconstruction using digital tools. Specifically, this paper examines an instructional activity conducted with first-year undergraduate students in the Department of Audio and Visual Arts, Ionian University (Greece), within the course Mathematics and Art. Students were asked to reconstruct selected modern artworks by the Greek artist Yiannis Moralis using linear and quadratic functions in GeoGebra.

Moralis' abstract compositions feature dominant

linear and curvilinear forms, geometric balance, and clear structural organization. These characteristics make his works particularly suitable for mathematical reconstruction, as they allow artistic form to be meaningfully approximated through first- and second-degree polynomial functions and domain restriction.^{38–40} Importantly, the use of Moralis' artworks is not decorative but epistemically grounded: the artworks constitute a mathematically coherent visual corpus that supports exploration of the relationship between algebraic functions and visual structure.

Despite the growing literature on STEAM education, dynamic mathematics environments, and mathematics–art integration, three interrelated gaps remain. First, art is often incorporated into mathematics education as an illustrative, ornamental, or motivational resource, whereas fewer studies examine contexts in which learners actively analyze and reconstruct artistic forms through mathematical representations and digital technologies.^{41,42} Second, existing research has more frequently focused on school-level or STEM-oriented populations than on arts-based undergraduates who may not identify themselves as mathematically capable. Third, limited qualitative attention has examined how reconstructing culturally situated artworks can reposition mathematical functions from abstract symbolic expressions to tools for visual interpretation, aesthetic judgment, and creative production.

The closest published precedents nevertheless differ in population, mathematical focus, and evidential design. Aktümen and Yıldız²² examined the design processes of preservice mathematics teachers who created aesthetically organized GeoGebra constructions; Abar *et al.*³⁸ investigated connections between arts and mathematics through isometric transformations; and Rizzo *et al.*⁴³ linked photography and mathematics through technology. The present study makes a deliberately modest, context-specific contribution by examining first-year audiovisual arts students reconstructing a culturally situated corpus of works by Yiannis Moralis through domain-restricted functions and by combining reflective narratives with direct structural analysis of the submitted GeoGebra artifacts.

The present study addresses these gaps through a case study in higher education in the Audio and Visual Arts. Its originality lies not merely in juxtaposing mathematics and art, but in examining how students with predominantly arts-oriented disciplinary identities negotiate mathematical meaning when functions become the means through which artistic form is analyzed, approximated, and recreated. Moralis' geometrically structured compositions provide

a particularly productive context because they support translation among visual form, algebraic representation, and creative judgment. The study therefore contributes qualitative evidence concerning the cognitive, affective, and interdisciplinary processes through which mathematics may become an expressive medium for learners who do not initially identify strongly with the discipline.

The mathematical focus of the activity was intentionally limited to foundational concepts in order to prioritize visualization, interpretation, and creative exploration over technical complexity. This design choice aligns with research emphasizing accessibility, representational clarity, and conceptual focus in interdisciplinary mathematics learning.^{21,44,45} Within this context, GeoGebra functioned as both a mathematical visualization tool and a creative digital laboratory, supporting experimentation, parameter manipulation, and iterative refinement of mathematical models.^{43,46,47}

This study does not aim to measure learning gains quantitatively, but to examine how students described their cognitive, affective, and interdisciplinary experiences and how these accounts related to the mathematical constructions they produced. The study therefore focuses on retrospective perceptions, representational decisions, and the coordination of mathematical and artistic practices rather than on causal claims of attitudinal or cognitive change.^{21,48,49}

The remainder of this paper is organized as follows. **Section 2** presents the theoretical framework underpinning the study, drawing on constructivist pedagogy, affective learning theories, aesthetics, and interdisciplinary educational approaches. **Section 3** describes the qualitative case study design, including the instructional context, participants, learning activity, and data analysis procedures. **Section 4** presents the qualitative findings, organized around key thematic categories. **Section 5** discusses the implications of the findings in relation to existing literature and limitations, while **Section 6** concludes the paper by outlining pedagogical contributions and directions for future research.

2. Theoretical framework

The present study is grounded in a theoretical framework that brings together constructivist pedagogy, affective learning theories, interdisciplinary approaches to education, and the role of digital tools as mediators of learning. This combination reflects the dual cognitive and emotional nature of learning mathematics in creative contexts and supports the integration of artistic practices into mathematical instruction through digital technologies.^{4,10,20} By synthesizing these perspectives, the

framework acknowledges learning as an active, situated, and meaning-making process shaped by interaction, emotion, and cultural context.^{8,30}

2.1. Constructivist perspectives on learning mathematics

Constructivist learning theory posits that knowledge is actively constructed by learners through interaction with concepts, tools, and experiences rather than passively received from instruction.^{8,10} In mathematics education, constructivist approaches emphasize exploration, experimentation, and meaning-making, allowing students to develop conceptual understanding by engaging directly with mathematical objects and representations.^{14,45} Rather than focusing solely on procedural fluency, constructivist pedagogy prioritizes the development of intuition, reasoning, and personal sense-making, particularly through visual and representational activity.^{9,13}

Dynamic mathematics environments such as GeoGebra align naturally with constructivist principles. By enabling learners to manipulate parameters, observe immediate visual feedback, and iteratively refine their constructions, these environments support exploratory learning, conjecture formation, and hypothesis testing.^{13,18} Students are encouraged to experiment with mathematical relationships, identify patterns, and adjust their models based on visual and conceptual cues, fostering a deeper integration of algebraic and geometric reasoning.^{14,17} In this context, mathematical functions are not presented as static formulas but as flexible tools for constructing, exploring, and interpreting visual forms.^{16,46}

In the present study, constructivist principles underpin the instructional design, as students actively reconstructed artistic forms through mathematical modeling. Knowledge construction occurred through hands-on interaction with functions, graphs, and domains, allowing students to build understanding through trial, error, and reflection rather than through direct instruction alone.^{35,37} This approach aligns with research emphasizing learner agency, exploration, and representational fluency as central components of meaningful mathematics learning.^{21,44,45}

2.2. Affective dimensions of mathematical learning

Beyond cognitive processes, affective factors such as motivation, confidence, enjoyment, and anxiety strongly influence mathematics learning.^{2,30} Research in mathematics education has consistently shown that negative emotional experiences can hinder engagement and limit students' willingness to persist in problem-solving tasks, particularly among learners who do not identify strongly with mathematics.^{1,4,31} These challenges

are especially pronounced among students from non-STEM or humanities-oriented backgrounds, who may perceive mathematics as inaccessible or disconnected from their interests.^{26,27}

Affective learning theories emphasize the role of emotions and attitudes in shaping learning experiences and outcomes. When learners experience enjoyment, curiosity, and a sense of achievement, they are more likely to engage deeply with content and develop positive, sustained relationships with the subject matter.^{28–30} Conversely, feelings of frustration, inadequacy, or alienation can lead to avoidance and disengagement, reinforcing negative cycles of learning.^{3,32}

Integrating artistic practices into mathematics education has been proposed as a powerful means of addressing affective barriers by providing emotionally meaningful and personally relevant contexts for learning.^{12,20} Artistic activities allow learners to express identity, creativity, and interpretation, thereby fostering a sense of ownership over the learning process.^{21,22} When mathematics is embedded within creative tasks, students may reframe their understanding of the discipline, perceiving it as flexible, expressive, and open to exploration rather than rigid and purely formal.^{10,33}

In this study, affective learning is central. The reconstruction of artworks using mathematical functions was designed not only to support conceptual understanding but also to encourage positive emotional engagement. Student reflections and feedback provide insight into how creative mathematical activities can influence attitudes toward mathematics, particularly in terms of confidence, enjoyment, perceived relevance, and emotional connection to mathematical ideas.^{31,49}

2.3. Interdisciplinarity and Science, Technology, Engineering, Arts, and Mathematics-oriented approaches

Interdisciplinary education seeks to bridge traditional disciplinary boundaries by integrating concepts, methods, and perspectives from multiple fields in order to promote deeper understanding and relevance.^{5,20} Within mathematics education, interdisciplinary approaches aim to situate mathematical concepts within broader cultural, artistic, or real-world contexts, thereby enhancing meaning-making and learner engagement.^{7,19}

The integration of mathematics and art is a well-established interdisciplinary domain, grounded in shared concepts such as geometry, symmetry, proportion, abstraction, and visual structure.^{5–7} Artistic works often embody mathematical structures implicitly, offering rich opportunities for mathematical exploration through visual

analysis and modeling.^{23–25} When students engage with art mathematically, they can uncover underlying structural relationships while simultaneously developing aesthetic awareness and interpretive sensitivity.^{8,10}

Science, Technology, Engineering, Arts, and Mathematics education extends this interdisciplinary philosophy by explicitly incorporating the arts into STEM learning. Rather than treating artistic elements as supplementary or decorative, STEAM approaches position creativity as central to inquiry, problem-solving, and innovation.^{19–21} Digital tools play a crucial role in enabling such integration, as they allow learners to experiment across domains within a unified representational environment.^{11,16}

In this study, GeoGebra serves as a mediating tool that bridges mathematics and art. By enabling the translation of visual forms into mathematical representations, the software supports both intradisciplinary connections (e.g., between algebra and geometry) and interdisciplinary connections between mathematics and artistic composition.^{13,18} The selection of Yiannis Moralis' artworks, characterized by abstract geometric forms and structural clarity, further reinforces this connection by providing a coherent visual corpus that lends itself naturally to mathematical reconstruction.^{38–40}

Research on mathematics and the arts distinguishes between using art as a supplementary illustration and more epistemically integrated approaches in which artistic and mathematical practices jointly structure learning. Reviews of curriculum materials indicate that ornamental applications, measurement activities, and illustrations of established concepts often predominate over tasks requiring the mathematical analysis of artworks or the creation of art through mathematical and technological means.⁴² This distinction is important because the depth of integration depends on whether learners merely identify mathematics within an existing artwork or actively translate, model, and reconstruct its visual structures.

Meaningful integration also requires preserving the disciplinary character of both mathematics and visual art. Investigative learning environments can support this aim by treating observation, construction, revision, and aesthetic evaluation as interdependent practices, rather than positioning art as decoration or mathematics as a purely technical device.⁴¹ In the present study, students did not simply identify geometric features in Moralis' paintings; they used mathematical functions to make interpretive decisions, generate visual forms, and evaluate the correspondence between algebraic models and artistic compositions.

2.4. Digital tools as mediators of visual and conceptual learning

Digital learning environments can function as cognitive and creative mediators, shaping how learners interact with abstract concepts and representations.^{4,16} In mathematics education, visualization tools have been shown to support conceptual understanding by making invisible relationships visible, dynamic, and manipulable.^{14,45} Such tools enable learners to coordinate multiple representations, fostering deeper insight into mathematical structure and meaning.^{13,44}

GeoGebra, in particular, allows for the simultaneous representation of algebraic expressions, graphical forms, and geometric constructions, supporting multiple modes of reasoning and learning.^{13,19} In this study, GeoGebra is conceptualized not merely as a technical tool but as a digital learning space that facilitates exploration, creativity, and reflection. Its accessibility and low technical barrier enable students with diverse backgrounds to engage meaningfully with mathematical content without requiring advanced programming or prior expertise.^{43,46,47}

As such, GeoGebra functions as a digital laboratory in which mathematics becomes a medium for creative inquiry rather than an isolated symbolic system. This mediating role is especially important in interdisciplinary and affectively oriented learning contexts, where visualization, experimentation, and aesthetic engagement are central to the learning experience.^{21,22,30}

2.5. Mathematical modeling as visual-artistic reconstruction

Mathematical modeling provides an additional conceptual lens for understanding the reconstruction activity. Modeling is commonly conceptualized as an iterative process through which a referent is interpreted, simplified, translated into mathematical representations, processed mathematically, and subsequently evaluated in relation to the original context. Although modeling cycles are frequently discussed in relation to real-world problems, their central processes are also applicable to visual and cultural artifacts when learners must determine which features are mathematically salient, select suitable representations, and evaluate the adequacy of the resulting model.^{50,51}

In the present activity, the selected artwork served as the extra-mathematical referent. Students identified visually salient structures, including line segments, curves, boundaries, and compositional relationships; simplified these structures; and translated them into linear or quadratic functions with restricted domains. Parameter manipulation involved work within the

mathematical model, whereas continuous comparison with the source artwork supported interpretation and validation. Discrepancies between the generated graph and the visual form prompted successive revisions of functions, parameters, and domains. The activity therefore involved processes associated with mathematical modeling, including identifying and simplifying relevant features, mathematizing visual relationships, coordinating algebraic and graphical representations, interpreting outputs in relation to an artistic referent, evaluating visual and mathematical adequacy, and iteratively revising the model.^{50,51}

2.6. Mathematical creativity in open-ended modeling

Mathematical creativity in educational contexts involves generating, varying, evaluating, and refining mathematical ideas rather than reproducing predetermined procedures. Contemporary scholarship identifies multiple conceptions of mathematical creativity, including fluency, flexibility, originality, elaboration, divergent thinking, and creative mathematical reasoning. It also emphasizes that conclusions concerning creativity depend on how the construct is theoretically defined and empirically evidenced.⁵² Creativity is therefore not restricted to the production of entirely novel mathematics, but may also be expressed through personally meaningful decisions and the adaptive use of familiar concepts in an unfamiliar context.

The reconstruction task provided conditions for this form of creative mathematical activity without requiring advanced mathematical content. Students could experiment with alternative functions, modify parameters, combine representations, restrict domains in different ways, and decide what level of visual approximation they regarded as satisfactory. The task therefore created opportunities for creativity through the flexible orchestration and elaboration of existing mathematical knowledge. The artistic referent also introduced aesthetic criteria into mathematical decision-making, as students evaluated not only whether a function was mathematically valid but also whether it generated a visually coherent form.

Taken together, these perspectives frame mathematical learning as an active, affectively charged, interdisciplinary, modeling-based, and potentially creative process. They provide the conceptual foundation for the instructional design and qualitative methodological choices described in the following section.

3. Methodological design

This study adopts a qualitative case study design to investigate how integrating mathematics and visual art,

mediated through GeoGebra, shapes students' cognitive, affective, and interdisciplinary learning experiences. Qualitative case study approaches are particularly appropriate for examining learning processes, emotional engagement, and meaning-making in context-specific educational settings, where phenomena are embedded in authentic instructional environments and cannot be meaningfully isolated from their sociocultural context.^{24,31,34} Such approaches are widely used in mathematics education research to capture learners' experiences, interpretations, and representations beyond measurable performance outcomes.³⁷

The instructional design centers on the mathematical reconstruction of selected artworks by the Greek modernist painter Yiannis Moralis (1916–2009) using GeoGebra. Moralis' mature artistic language is characterized by abstraction, compositional balance, and the reduction of figurative elements to geometric forms, aligning closely with concepts such as symmetry, proportion, and structural decomposition that have been widely discussed in the literature on mathematics and art.^{5–7} These characteristics render his work particularly suitable for mathematical modeling through linear and quadratic functions, domain restriction, and analytic geometry.^{23–25} Importantly, the selection of Moralis' artworks was not aesthetic alone but epistemic: the artworks constitute a visually coherent corpus that supports meaningful translation between artistic form and mathematical structure.^{8,10}

This artistic and technological framing directly informed the research design, instructional activity, and analytic focus described in the following subsections.

3.1. Research design and participants

The study employed a qualitative, exploratory case study design, appropriate for examining learning processes, emotional engagement, and interdisciplinary meaning-making in digitally mediated educational contexts.³⁴ The case study was implemented during the winter semester of the 2024–2025 academic year in the undergraduate course Mathematics and Art, offered by the Department of Audio and Visual Arts, Ionian University, Corfu, Greece.

The primary instructional objective of the course component examined in this study was to reconstruct selected Moralis artworks using GeoGebra, with the software serving as both a mathematical visualization environment and a creative digital laboratory.^{13,18} Beyond technical modeling, the activity aimed to explore how students negotiated mathematical meaning, emotional engagement, and interdisciplinary connections between mathematics and visual art, consistent with STEAM-oriented educational approaches.^{19–21}

The study was guided by the following research questions:

- Research question 1 (RQ1): What affective experiences did students describe during and after the GeoGebra-based reconstruction activity?
- Research question 2 (RQ2): How did students retrospectively describe their relationship with mathematics in connection with the activity?
- Research question 3 (RQ3): What forms of mathematical and representational activity are evidenced in students' narratives and GeoGebra constructions?

These questions were addressed through qualitative analysis of students' reflective narratives and digital artifacts produced during the modeling process, following established practices in qualitative mathematics education research.^{35–37}

The course enrolled 72 first-year undergraduate students. The semester assignment was compulsory and contributed 30% of the final course grade; however, students could select freely from 18 proposed topics or request approval for a related alternative. Topic 18 concerned reconstructing a work by Yiannis Moralis using GeoGebra. 14 students selected and submitted this topic (19.4% of the enrolled cohort). Written files were available for 13 of these submissions; one was empty and was excluded, yielding 12 analyzable reflective narratives. 12 accessible GeoGebra files were available for artifact analysis, and 11 participants provided both an analyzable narrative and a GeoGebra construction. The analyzed material therefore represents a topic-selected subsample rather than the full cohort. The remaining 58 students did not reject or fail to complete the semester assignment; they selected other topics from the common assignment list. Throughout the analysis, participants are identified using the codes S01–S14.

All students received the GeoGebra presentation, guided use, and introductory training as a compulsory part of the first-year course. The researcher delivered this instruction rather than the principal course instructor. Research participation was linked specifically to the optional selection of Topic 18, not to participation in the compulsory GeoGebra instruction. The assignment announcement informed students in advance that submissions produced under Topic 18 could be used in anonymized form for research purposes and to prepare and publish a scientific article. Selection of Topic 18 was voluntary, and students who did not wish their work to be included in the research corpus could select any of the other 17 proposed topics or request approval for a related alternative. Only anonymized submissions were included in the analysis and reporting. The researcher was not the

principal instructor for the course, although her role in introducing the tool and supporting the activity created a pedagogical relationship that is acknowledged in the positionality and limitations statements.

3.2. Instructional design and learning activity

No advanced prior familiarity with GeoGebra was assumed. All 72 first-year students participated in the compulsory introductory training delivered by the researcher. The sequence lasted four weeks (two teaching hours per week) and covered the Toolbar, Algebra View, Graphics View, Input Field, points, lines, functions, sliders, and domain restrictions. After this common preparation, students selected one of the 18 semester-assignment topics. The 14 students who chose Topic 18 subsequently worked individually and autonomously on the Moralis reconstruction, with formative guidance available during laboratory sessions and asynchronously.

Students received a set of 12 digitized works by Yiannis Moralis, labeled Moralis2–Moralis13 for instruction and file management. These labels were not presented as official artwork titles. Students were free to select any image from the provided set or to choose another work by Moralis identified independently online; no work was individually assigned. The choice was therefore student-directed and could reflect visual interest, perceived feasibility, or personal preference. [Appendix A](#) shows the instructional set and the status of available title identifications.

A case-level comparison of the submitted files and embedded reference images allowed 12 of the 14 submissions to be matched to an instructional image; [Appendix A](#) reports the selection distribution. Two submissions could not be assigned confidently because no locally accessible GeoGebra file or source image was available.

The selected image was imported into the GeoGebra Graphics View, positioned relative to the Cartesian coordinate system, scaled, and rendered semi-transparent so that mathematical curves could be superimposed while the underlying composition remained visible. The mathematical focus was initially placed on linear functions:

$$f(x) = ax + b \quad (1)$$

and quadratic functions:

$$f(x) = ax^2 + bx + c \quad (2)$$

Students were shown how changes in the coefficients affected slope, curvature, position, and orientation, and how sliders supported exploratory parameter adjustment.

Local contours were represented by restricting the visible portion of a graph, typically through a conditional expression of the form:

$$f(x) = \text{If}[a \leq x \leq b, g(x)] \quad (3)$$

Students compared the generated curve with the visual referent and successively revised the function type, coefficients, or interval endpoints. Vertical elements could be represented through line segments or equations of the form $x = c$, while circles, semicircles, conic sections, polygons, and fitted curves could be used when these provided a more appropriate representation. The submitted constructions show that some students retained this broader set of representations even though the introductory mathematical content emphasized linear and quadratic functions.

The task was framed as an iterative modeling activity rather than as pixel-level tracing. Students identified visually salient features, selected mathematical representations, inspected discrepancies between the graph and the artwork, and refined their models. No numerical tolerance or formal pixel-matching criterion was imposed. Adequacy was judged qualitatively through the mathematical interpretability of the construction and the correspondence of its principal contours and compositional relationships with the selected visual referent.

3.3. Data collection

The study drew on two principal data sources from the 14 Topic 18 submissions: (i) reflective written narratives produced after completion of the activity and (ii) the submitted GeoGebra files. The narrative corpus contained 12 analyzable texts. The digital-artifact corpus contained 12 accessible «.ggb» files. Both sources were available for 11 participants, enabling case-level comparison of self-report and produced mathematical representations. The remaining course assignments, which addressed other topics, were not included in the present study.

The post-activity questionnaire was provided as an optional reflective aid rather than as a graded instrument. One participant completed it in its original question-and-answer format, whereas other participants used its prompts as a guide for a freer narrative account. Both formats were accepted because the purpose was to support open expression rather than to impose a uniform response structure. The reconstruction itself, specifically, the student's engagement with GeoGebra and the extent to which the intended visual result was achieved, was assessed by the principal instructor and contributed 30% of the

final course grade. The reflective narrative was not graded. [Appendix B](#) reproduces the prompts verbatim. Only one complete paired pre- and post-activity questionnaire was available; it is treated as an illustrative case and is not used to make group-level claims of change. The remaining findings concerning affect and attitudes are based on retrospective post-task accounts.

The narratives were written and analyzed in Greek. The researcher translated excerpts selected for the English-language manuscript as close semantic renderings of the original statements. The translation avoided intentional paraphrase or interpretive expansion; minor syntactic adjustments were made only as needed for grammatical clarity in English while preserving the original meaning, tone, and affective content.

The instructional images were obtained from publicly accessible online sources and used as visual reference material within the educational activity. To avoid reproducing a protected Moralis image in this paper, the published figure displays only the student-generated mathematical overlay and the corresponding algebraic expressions; the original artwork used as the GeoGebra background has been removed.

3.4. Data analysis

The 12 analyzable narratives were examined using reflexive thematic analysis following Braun and Clarke's framework and subsequent methodological clarifications concerning researcher subjectivity, recursive analysis, and quality.^{35,53–57} The unit of analysis was each participant's complete written account. Analysis involved familiarizing the Greek-language texts, generating semantic and interpretive codes, cross-case comparison, developing and reviewing candidate themes, and finally defining and naming the thematic categories.

Coding was primarily inductive but was informed by the research questions and the theoretical concerns of digital mediation, representation, affect, mathematical modeling, creativity, and interdisciplinary meaning-making. The researcher was solely responsible for designing the activity, the compulsory GeoGebra instruction, its implementation, pedagogical supervision, data preparation, initial coding, theme development, and analysis of the digital artifacts. The principal course instructor did not participate in coding or interpretation of the narratives; his role was limited to the final academic evaluation of the submitted reconstruction. Consistent with reflexive thematic analysis, codes and themes were treated as interpretive constructions rather than objectively discoverable units requiring statistical coder agreement. We documented analytical decisions through reflexive notes, cross-case comparison, and explicit

examination of negative, incomplete, and contradictory cases.

As a supplementary descriptive step, we calculated theme-presence counts after theme development. A category was counted once for a participant when at least one passage in the narrative was coded within that category, irrespective of how many times it appeared in the same text. These counts indicate thematic distribution across the corpus; they do not measure intensity, importance, or learning gain and were not subjected to inferential statistical analysis.

The GeoGebra files were analyzed separately as structured digital artifacts. The internal construction data were examined to identify the number and type of mathematical objects, including functions, points, line segments, polygons, conics, numeric parameters, and embedded images. The analysis also recorded restricted expressions, visible sliders retained in the final file, and curve-fitting commands such as FitPoly. Counts were used descriptively and were not treated as measures of quality: a high object count could reflect numerous auxiliary points or a polygonal tracing strategy, whereas a lower count could represent a more economical function-based solution.

For the 11 participants with both an analyzable narrative and a GeoGebra file, a case-by-case triangulation matrix was used to compare reported difficulties, stated strategies, affective accounts, perceived learning outcomes, and objective artifact features. An illustrative coding pathway is shown in Table 1. The comparison attended to convergence, complementarity, and discrepancy. For example, a narrative could report temporary slider use even when the submitted file did not retain sliders. The full anonymized matrix is provided as **Supplementary File 1** (see Appendix C).

The primary researcher designed and delivered the compulsory GeoGebra training, implemented and supervised Topic 18, and conducted the qualitative and

artifact analyses, but she was not the principal instructor responsible for the course or the final grading decision. The principal instructor acted only as the final evaluator of the submitted reconstruction. This arrangement limited, but did not eliminate, the pedagogical power relation: the researcher's direct instructional and supervisory contact with the students may have influenced their reflective accounts and her interpretation of the data. Reflexive notes, explicit separation of descriptive artifact observations from interpretive claims, and active searches for negative, incomplete, and contradictory cases made this influence visible. Table 2 summarizes the alignment of the research questions, data sources, analytic procedures, and outcome categories.

4. Outcomes

The combined analysis of the reflective narratives and GeoGebra constructions revealed five interrelated outcome categories that illuminate how the participating students experienced and enacted the integration of mathematics and visual art through GeoGebra-mediated modeling. Within this corpus, mathematical activity extended beyond procedural execution to include tool appropriation, representational coordination, iterative problem-solving, affective experience, and interdisciplinary meaning-making.

The five outcome categories are:

- (i) Digital tool appropriation
- (ii) Mathematical and representational fluency
- (iii) Creative modeling and problem-solving
- (iv) Affective engagement and retrospective attitude accounts
- (v) Interdisciplinary mathematics–art meaning-making

These categories are analytically distinct but interconnected. Digital tool appropriation, mathematical and representational fluency, and creative modeling and problem-solving primarily address RQ3, drawing on evidence from both narratives and digital artifacts. Affective

Table 1. Illustrative coding pathway from data to outcome categories

Data excerpt or artifact observation	Initial code	Focused code	Outcome category
"The curves did not coincide with the design, so I used small straight lines."	Replacing curves with lines	Approximation through strategy revision	Creative modeling and problem-solving
Small parameter changes produced large visual differences.	Parameter sensitivity	Iterative parameter refinement	Mathematical and representational fluency
Vertical contours were represented using segments rather than functions.	Recognition of a non-function form	Switching representational system	Mathematical and representational fluency
Initial enthusiasm was followed by frustration and incomplete work.	Excitement followed by frustration	Ambivalent affective trajectory	Affective engagement and retrospective attitude accounts

engagement and retrospective attitude accounts address RQ1 and RQ2, while interdisciplinary mathematics–art meaning-making contributes to interpreting all three research questions. The categories are presented as situated patterns within the 12 analyzable narratives and the 12 accessible GeoGebra files, rather than as universal or independently measured outcomes.

Table 3 presents selected excerpts from the reflective narratives. The excerpts represent recurrent patterns, variation within the outcome categories, and negative or ambivalent experiences. They are illustrative rather than exhaustive, and researcher interpretation is kept separate from participants' words.

The excerpts show that positive accounts coexisted with frustration, incompleteness, and representational compromise; the thematic account therefore does not treat engagement or perceived change as uniform across participants.

4.1. Distribution of the outcome categories

Five consistently labeled outcome categories were used throughout the analysis: digital tool appropriation; mathematical and representational fluency; creative modeling and problem-solving; affective engagement and retrospective attitude accounts; and interdisciplinary mathematics–art meaning-making. The categories were not equally distributed across the 12 analyzable narratives. Mathematical and representational fluency appeared in all narratives, while affective accounts appeared in 11. Creative modeling and problem-solving were identified in 10 narratives, and both digital tool appropriation and explicit interdisciplinary meaning-making appeared in eight. These values indicate presence at least once in a narrative and should not be interpreted as measures of theme intensity or generalizable prevalence. Table 4 summarizes the descriptive distribution of these outcome categories.

Table 2. Alignment of research questions, data sources, and analytic procedures

Research question	Data source	Analytic procedure	Relevant outcome categories
Research question 1: What affective experiences did students describe during and after the activity?	12 reflective narratives	Reflexive thematic analysis; negative and ambivalent case analysis	Affective engagement and retrospective attitude accounts
Research question 2: How did students retrospectively describe their relationship with mathematics?	12 reflective narratives; one illustrative paired pre-post case	Retrospective account analysis; cautious comparison with initial self-description where available	Affective engagement and retrospective Attitude accounts; interdisciplinary mathematics–art meaning-making
Research question 3: What forms of mathematical and representational activity are evidenced?	12 GeoGebra files; 11 paired narrative-artifact cases	Structural artifact analysis; modeling-strategy analysis; case-level triangulation	Mathematical and representational fluency; creative modeling and problem-solving; digital tool appropriation

Table 3. Representative narrative excerpts by outcome category

Outcome category	Illustrative excerpts from students' narratives
Digital tool appropriation	"GeoGebra was my first introduction to computer geometry." "Through GeoGebra, I learned to see and construct mathematical functions visually and interactively."
Mathematical and representational fluency	"By observing multiple representations, such as algebraic, geometric, and graphical..." "I learned to understand the same mathematical concept in different ways." "Functions cease to be simple formulas and become tools for describing real shapes."
Creative modeling and problem-solving	"The curves did not coincide with the design, so I used small straight lines." "To overcome the difficulties, I used what I learned in class." "Despite the difficulties, I enjoyed all the stages of creation and the challenge."
Affective engagement and retrospective attitude accounts	"The first time I used GeoGebra, I was very pleased with the process since I did not have a good relationship with mathematics." "At first I was excited... several times I became frustrated... I did not manage to finish." "In the end, you are rewarded with the result."
Interdisciplinary mathematics–art meaning-making	"I never imagined there would be a tool that would allow me to use mathematics to make a painting." "It made me appreciate the beauty and utility of mathematics in art and geometry." "I want to deal with animation; GeoGebra helped me somewhat to get into this mood..."

4.2. Analysis of the GeoGebra constructions

Twelve GeoGebra constructions were available for artifact analysis. The files contained 1,119 mathematical objects in total, ranging from 27 to 259 objects per construction, with a median of 75. 11 files contained explicit functions, ranging from 9 to 70 per file, with a median of 29.5. Domain restriction was a central structural feature: 11 of the 12 constructions contained restricted expressions, and the corpus included 336 such expressions. 11 files retained an imported background image, five retained visible sliders, and three used polynomial curve-fitting commands.

The constructions did not exhibit a uniform approach. Four recurrent strategies emerged: dense reconstruction through numerous short domain-restricted functions; hybrid combinations of functions and geometric objects; polygonal and conic decomposition; and point-based polynomial fitting. Several files relied almost entirely on short linear or quadratic pieces. In contrast, one construction contained no functions and decomposed the composition into 22 polygons, 92 line segments, 126 points, and nine conic or conic-part objects. This variation

shows that the task elicited different representational decisions rather than a single prescribed solution path. Table 5 summarizes the structural characteristics of the analyzed GeoGebra constructions.

A closer examination of the submitted files showed that the reconstructions were typically produced by coordinating multiple local mathematical objects rather than through a single global equation. In many cases, visually meaningful contours were represented by separate linear or quadratic functions whose graphs were restricted to specific intervals. The selection of the function type, adjustment of coefficients, and determination of interval endpoints therefore formed an interconnected modeling process.

Figure 1 illustrates this algebraic-to-visual correspondence through a representative example from S12. The algebra panel displays selected domain-restricted linear and quadratic functions together with a circular equation, while the graphics panel presents the corresponding student-generated mathematical overlay without the original artwork background. The example

Table 4. Distribution of outcome categories across the analyzable narratives ($n = 12$)

Outcome category	<i>n</i>	%
Mathematical and representational fluency	12	100.0
Affective engagement and retrospective attitude accounts	11	91.7
Creative modeling and problem-solving	10	83.3
Digital tool appropriation	8	66.7
Interdisciplinary mathematics–art meaning-making	8	66.7

Note: Counted each category once per narrative if it appeared at least once. Percentages are descriptive and use the 12 analyzable narratives as the denominator.

Table 5. Structural characteristics of the analyzed GeoGebra constructions ($n = 12$)

Construction feature	Corpus total	Median per file	Range	Files with feature
Total mathematical objects	1,119	75	27–259	12/12
Functions	386	29.5	0–70	11/12
Points	394	15	2–126	12/12
Line segments	167	0	0–92	4/12
Polygons	22	0	0–22	1/12
Conics/conic parts	12	0	0–9	5/12
Restricted expressions	336	22.5	0–70	11/12
Retained visible sliders	47	–	0–23	5/12
Embedded background images	11	–	0–1	11/12
FitPoly applications	28	–	0–19	3/12

Notes: Counts characterize artifact structure and are not interpreted as indicators of quality or learning gain. “Retained sliders” refers to visible slider objects preserved in the final submitted file.

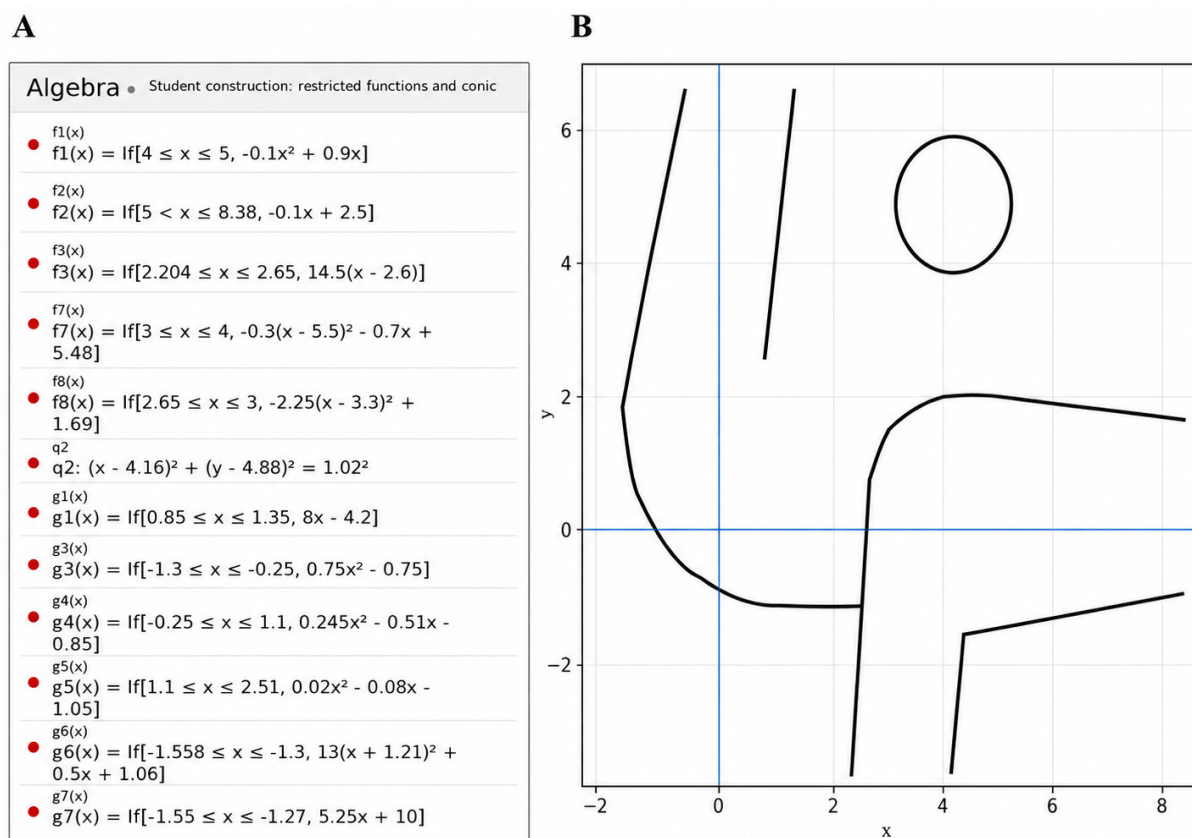


Figure 1. Algebraic-to-visual correspondence in participant S12's GeoGebra construction. (A) A representative selection of domain-restricted linear and quadratic functions and a circular equation from the algebra view. (B) The corresponding student-generated graphical overlay after removal of the original artwork background. The figure illustrates how local algebraic definitions were coordinated to generate visually meaningful contours. For readability, both (A) and (B) were prepared from the expressions and graphical objects contained in the original submitted GeoGebra file.

demonstrates the decomposition of a visual form into locally defined components, each associated with a particular contour or shape. Because each expression was defined over a limited interval, only the graph segment required for the local feature remained visible. The construction therefore emerged through repeated movement between algebraic definition, graphical inspection, and refinement of parameters or intervals.

The artifact evidence also revealed modeling trade-offs and representational constraints. Complex curves were sometimes approximated by multiple short linear pieces, increasing local visual correspondence while sacrificing smoothness. Vertical contours were represented by segments or equations of the form $x = c$ because they could not be expressed as single-valued functions $y = f(x)$. Some students used nearly vertical functions with very large slopes, which created zoom and visibility problems.

Visible sliders were retained in five files, but the narratives showed that participants sometimes used sliders during exploration and removed them after identifying suitable values. Final-file counts therefore underestimate process-level use.

4.3. Digital tool appropriation

Digital tool appropriation was evident in eight narratives and varied substantially. Several participants described first-time use, initial interface difficulty, software slowness, or problems working from a mobile device. Other accounts documented gradual familiarization with the algebra and graphics views, background-image opacity, sliders, intersections, and coordinate reading. The artifacts show that appropriation did not mean uniform use of all features: retained slider counts ranged from zero to 23, and some sophisticated constructions used fixed numerical values rather than dynamic controls.

4.4. Mathematical and representational fluency

All 12 narratives contained evidence of selecting, adjusting, combining, or restricting mathematical representations. The strongest artifact-based evidence involved domain restriction, coordinating algebraic and graphical views, and switching between representational systems. One participant explicitly recognized that vertical contours could not be represented as functions of x and used line segments instead; the corresponding file contained 56 functions and 16 segments. Other files combined quadratic functions, semicircle expressions, conics, polygons, or fitted curves. Mathematical literacy in this context therefore took the form of situated representational judgment rather than solely as correct symbolic manipulation.

4.5. Creative modeling and problem-solving

Creative modeling and problem-solving appeared in 10 narratives. Students described revising unsuccessful approaches, replacing difficult curves with short straight pieces, adjusting values to several decimal places, changing zoom or scale, using intersection points to delimit graphs, and abandoning an initial function-based strategy in favor of circles, semicircles, and polygons. These decisions provide qualitative evidence of flexibility and elaboration, but not of creativity as measured by a standardized instrument.

4.6. Affective engagement and retrospective attitude accounts

The affective accounts were mixed and often changed during the activity. Participants described curiosity, enthusiasm, frustration, anger, boredom, fatigue, persistence, disappointment, satisfaction, and incompleteness. Some students retrospectively reported that the activity broadened their view of mathematics or made mathematical work feel more connected to their artistic interests. Others entered

with an already positive relationship with mathematics, and at least one participant remained frustrated and did not complete the construction. These accounts should therefore be interpreted as retrospective descriptions rather than as measured pre-post attitude change.

4.7. Interdisciplinary mathematics-art meaning-making

Eight narratives explicitly articulated mathematics as an artistic or interdisciplinary medium. Students described the task as using mathematics to make an image, linked GeoGebra with animation or digital media, or reported seeing another dimension of mathematics. Such accounts indicate perceived connections across mathematical and artistic practices. They do not, however, establish transfer through independent performance measures.

4.8. Negative, ambivalent, and disconfirming cases

Negative and contradictory cases were retained as analytically important. One participant reported initial excitement followed by repeated frustration, time pressure, and failure to complete the work; the submitted file remained visibly incomplete and contained only nine restricted functions. Another described an initially difficult and unstable interface despite ultimately producing 66 functions. A third replaced curves with multiple short linear pieces because the intended functions did not align with the image. The polygonal construction containing no functions further contradicted a uniform function-centered trajectory. These cases demonstrate that persistence, visual success, positive affect, and intended mathematical strategy did not always coincide. Table 6 summarizes these negative, ambivalent, and disconfirming cases.

Excerpts were selected to represent recurrent patterns, variation within themes, and cases that challenged the

Table 6. Illustrative negative, ambivalent, and disconfirming cases

Case	Narrative evidence	Artifact evidence	Analytic significance
S07	Repeated frustration, time pressure, and non-completion	Nine restricted functions and 14 retained sliders; incomplete construction	Engagement and persistence did not ensure successful completion or a positive experience
S04	Interface difficulty, slowness, and unexpected malfunctions	66 restricted functions	Technical frustration coexisted with extensive production and later appropriation
S03	Curves did not align with the image	26 restricted functions, largely short pieces	Visual correspondence was prioritized through a piecewise linear approximation trade-off
S05	Initial parabolic strategy was abandoned	No functions; 22 polygons, 92 segments, 126 points, nine conic elements	Contradicts a uniform function-centered trajectory and shows representational strategy revision
S13	Anger, boredom, and fatigue; no explicit positive outcome	No accessible “ggb” file	Provides a persistently negative/ambivalent narrative that cannot be verified as an artifact.

dominant interpretation. Selection was not based on positivity or rhetorical vividness alone. Combining narratives and artifacts made it possible to include incomplete, technically difficult, and representationally divergent cases rather than presenting only successful or affirming accounts.

5. Discussion

The combined narrative and artifact analysis refines the study's contribution in three respects. First, the activity is best understood as local and iterative mathematical modeling. Students repeatedly selected a representation, restricted its visible domain, inspected the generated contour, and revised the function, parameters, or representation. This cycle was observable in the submitted files and was not inferred solely from retrospective accounts. The artifact evidence therefore supports a more precise claim than the original manuscript: the activity created opportunities for representational judgment and revision, although it does not demonstrate generalized conceptual gain.

Second, the constructions highlight the importance of representational choice and approximation. Students did not uniformly use linear and quadratic functions. Some relied on dense collections of restricted functions, others combined functions with segments or conics, and one decomposed the image into polygons and circular forms. They frequently simplified complex visual contours, approximated them piecewise, or generated them through polynomial fitting. These strategies show that mathematical adequacy and visual correspondence sometimes competed, requiring trade-offs rather than a single correct model.

Third, the affective findings show complexity rather than uniform transformation. Several participants retrospectively described satisfaction, increased confidence, or a broader view of mathematics, but the corpus also contains frustration, boredom, fatigue, technical difficulty, and incompleteness. The data therefore support claims about reported affective experiences and perceived shifts for some participants, not causal claims that the activity reduced anxiety or produced positive attitudes across the group. Flow was not measured and is not claimed as an empirical outcome.

The interdisciplinary contribution is similarly modest but specific. For some students, the task made mathematical expressions available as visual and artistic resources and connected GeoGebra with animation, design, or digital-media interests. This suggests that a culturally situated visual referent can create a context in which algebraic and geometric representations acquire artistic meaning. The evidence concerns perceived and enacted connections

within this case rather than independently assessed transfer to new contexts.

The study's originality therefore lies mainly in combining an arts-oriented undergraduate cohort, a culturally specific artistic corpus, and direct analysis of the mathematical constructions produced. It extends prior work on GeoGebra-based artistic reconstruction by documenting how students negotiated domains, vertical contours, local approximation, curve fitting, and alternative geometric strategies, and by showing where narrative accounts converged with or diverged from the submitted artifacts.

This study has several limitations. The corpus composition constrains the findings. Although all 72 enrolled students received the same compulsory GeoGebra introduction, only 14 selected Topic 18 from the 18 available semester-assignment topics. The analyzed group may therefore have differed from students selecting other topics in their interest in digital mathematics, confidence, aesthetic preference, or perceived feasibility. Of these, 12 provided analyzable narratives, and 12 had accessible GeoGebra files; therefore, the findings cannot be generalized to the full cohort. The study did not examine the educational experiences or outcomes associated with the other 17 assignment topics.

Most affective and attitudinal evidence consists of retrospective self-report collected after the activity. Only one complete paired pre-post questionnaire was available, and no validated measures of attitude, anxiety, flow, creativity, or achievement were administered. References to confidence, enjoyment, creativity, or perceived change should therefore be read as situated participant accounts rather than measured psychological or cognitive outcomes.

The semester assignment was compulsory and contributed 30% of the final course grade, but students freely selected from 18 proposed topics. For Topic 18, only the GeoGebra reconstruction was graded; the reflective narrative and the optional questionnaire were not evaluated and did not affect the course grade. The researcher designed, taught, implemented, and supervised the GeoGebra activity, while the principal instructor served as the final evaluator. Students were informed in advance that submissions produced under Topic 18 could be used in anonymized form for research and publication purposes. Students who did not want their work to be included in the research corpus could select one of the other 17 proposed topics or request approval for a related alternative. This arrangement reduced direct pressure to participate in the research topic but did not entirely remove the power asymmetry inherent in a graded course or the possibility of socially desirable reflection.

The corpus was incomplete and uneven across cases: 11 participants provided both data sources, one provided only an artifact, and two provided written material without an accessible local GeoGebra file. Final artifact files also do not preserve every process action; temporary sliders or abandoned attempts may be absent. Object counts describe the submitted structure and should not be interpreted as direct measures of quality or understanding.

The researcher translated the narratives without an independent bilingual review. The translations sought close semantic correspondence with the original Greek statements and avoided intentional paraphrase or interpretive expansion; nevertheless, subtle linguistic and affective nuances may have been affected. In addition, the figure in the manuscript does not reproduce the original Moralis artwork: the background image was removed, and only the student-generated mathematical expressions and graphical overlay are shown.

6. Conclusion and future work

This study examined how a small, self-selected group of first-year audiovisual arts students used GeoGebra to reconstruct compositions by Yiannis Moralis. The central finding is not that the activity uniformly transformed attitudes or improved achievement, but that it elicited iterative decisions about representation. Students selected mathematical forms, restricted domains, evaluated visual mismatch, and revised parameters or strategies. Their constructions ranged from economical function-based models to dense piecewise, polygonal, conic, and point-fitting approaches.

The affective accounts were similarly varied. Some participants described satisfaction, confidence, or a broadened view of mathematics; others described frustration, fatigue, boredom, technical problems, or incompleteness. The study therefore provides evidence of representational experimentation and retrospective affective engagement, but not of group-level learning gains or measured attitude change.

6.1. Pedagogical contributions

The activity offers a replicable structure for connecting foundational mathematics with visual-art practice: students work with an imported semi-transparent image, model local contours through functions or geometric objects, restrict domains, and refine the construction through immediate graphical feedback. The approach may be especially useful where the pedagogical goal is to make relationships among algebraic, graphical, and visual representations experientially accessible. Its value depends on adequate scaffolding, time, software access, and explicit

permission to use alternative representations when a function is unsuitable.

6.2. Directions for future research

Future studies should recruit a larger, more complete cohort to separate research participation from graded assessment, and include performance-based mathematical measures alongside validated affective instruments where claims of change are intended. Process data such as screen recordings, GeoGebra construction protocols, version histories, or think-aloud interviews would provide stronger evidence of how representations and strategies develop over time. Comparative designs could examine arts-oriented and STEM cohorts, individual and collaborative studio formats, and different visual corpora.

The present case supports a measured conclusion: GeoGebra-based artistic reconstruction can create a setting in which mathematical expressions and geometric objects become resources for visual interpretation and creative production. The experience is not uniformly accessible or transformative, but it can reveal forms of mathematical participation that are difficult to observe through self-report alone when narrative and digital-artifact evidence are analyzed together.

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Conflict of interest

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Author contributions

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Writing — original draft: Nymfodora Voulgari
 Writing — review & editing: Michail Panagopoulos

Ethics approval and consent to participate

The study was conducted within a regular university course and involved anonymized educational materials generated as part of normal teaching activities. No separate institutional ethics approval reference number was issued for this study. Students were informed in advance that submissions produced under Topic 18 could be used in anonymized form for research and publication purposes. Selection of Topic 18 was voluntary, and students could instead select one of the other 17 proposed assignment topics or request approval for a related alternative. The reflective narratives and questionnaire responses were not graded, and all materials were anonymized prior to analysis and reporting.

Consent for publication

None.

Availability of data

None.

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Appendix

Appendix A

Moralis artworks offered for student selection

The instructional codes Moralis2–Moralis13 were file-management labels, not official titles. Where an institutional source allowed reliable identification, the verified title is reported; otherwise, the original instructional code is retained to avoid assigning an unsupported title solely from visual resemblance.

Instructional code	Closest identification and verification status	Matched anonymized cases	<i>n</i>
Moralis2	Dialogue (1974) verified through an institutional collection	S07	1
Moralis3	Official title not independently verified; instructional code retained	S01	1
Moralis4	Erotic (1988) closest exact visual match located online; title/date not institutionally verified	S04	1
Moralis5	Erotikon/erotic composition closest exact visual match located online; date not independently verified	–	0
Moralis6	Full Moon M (1977–1978) verified through an institutional collection	S08, S09, S10, S12	4
Moralis7	Girl Undoing Her Sandal (1973) verified through an institutional collection	S11	1
Moralis8	Official title not independently verified; instructional code retained	S05	1
Moralis9	Official title not independently verified; instructional code retained	–	0
Moralis10	Official title not independently verified; instructional code retained	–	0
Moralis11	Official title not independently verified; instructional code retained	S02, S03, S06	3
Moralis12	Official title not independently verified; instructional code retained	–	0
Moralis13	Erotic (1982) closest exact visual match located online; title/date not institutionally verified	–	0
Unresolved submission	Source artwork not recoverable from the locally available materials. S13 contained an external GeoGebra link but no accessible local file; S14 contained only a brief written note.	S13, S14	2

Notes: Selection counts refer to the 14 Topic 18 submissions. Matching was based on the reference image embedded in each accessible GeoGebra file or, for S05, on the submitted geometric reconstruction. We could not identify S13 and S14 because the locally available submission materials did not contain a recoverable source image. We retain the full distribution in the appendix because it documents corpus composition without interrupting the main results narrative.

Appendix B

Pre- and post-activity questionnaires

B1. Pre-activity questionnaire

1. How familiar are you with GeoGebra? (Not at all – Slightly – Moderately – Very – Extremely)
2. Do you have any previous experience using mathematical software? (Yes/no). If yes, please specify which software you have used.
3. How comfortable do you feel with the graphical representation of functions? (Not at all – Slightly – Moderately – Very – Extremely)
4. How would you describe your general relationship with mathematics? (Positive – Neutral – Negative)
5. How do you feel about the use of digital tools in mathematics education?
6. What are your expectations regarding the GeoGebra-based task?
7. Do you believe that integrating mathematics and art can facilitate the understanding of mathematical concepts? Please explain your answer.

B2. Post-activity reflective prompts

1. To what extent did GeoGebra support your understanding of linear and quadratic functions?
2. Can you explain, in your own words, how the parameters *a*, *b*, and *c* affect the graphical form of a function?
3. Do you feel that you developed skills in constructing graphical representations through the use of functions?
4. How would you describe your emotional experience while completing the task? Please refer to different stages of the

process, any difficulties encountered, and aspects that you found enjoyable.

5. Did you experience feelings of enthusiasm, frustration, or satisfaction during the task? Please describe your experience.
6. To what extent did the task help you perceive mathematics from a different perspective?
7. Do you believe that the process can be described as “painting with formulas”? Please explain your response.
8. To what extent did the integration of mathematics and art influence your learning experience?

B3. Use of questionnaire data

The written responses to the post-activity prompts formed the reflective narratives and the primary textual dataset for reflexive thematic analysis. Open-ended responses concerning students’ learning processes, emotional experiences, perceived attitudinal changes, creativity, and interdisciplinary meaning-making were coded and interpreted thematically. By contrast, responses to the pre-activity questionnaire, including its closed-ended and structured items, were used only as descriptive context and were not incorporated into the thematic coding. This distinction ensured that the identified themes remained grounded in students’ elaborated written accounts while allowing their prior familiarity, attitudes, and expectations to inform the interpretation of those accounts.

Appendix C

Supplementary case-by-case triangulation matrix

A full anonymized matrix for S01–S14, including source availability, objective GeoGebra features, reported difficulties, problem-solving strategies, affective accounts, perceived learning outcomes, and cross-source interpretations, is supplied as **Supplementary File 1**.