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CHALLENGES AND OPPORTUNITIES IN FUNCTION ART

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ABSTRACT

Aim/Purpose	This study explored the limited research on the challenges and opportunities faced by students when creating function art using GeoGebra, addressing a gap in the literature that focuses on student outputs and engagement. It addressed the need to understand how students engage with function art and the difficulties they encounter in this process.
Background	Function art is a mathematical art form in which graphs of mathematical functions are used to create artistic designs. This study investigated the experiences of students in using GeoGebra for function art.
Methodology	The research employed a qualitative case study approach, analyzing survey responses from 111 Grade 11 students. The study focused on their experiences, challenges, and insights while creating function art using GeoGebra.
Contribution	This paper contributes to the understanding of how students interact with function art. It highlights the challenges students encounter in creating function art.

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Findings	Students faced difficulties related to mathematical knowledge, hardware limitations, software accessibility, and internet connectivity.
	Despite challenges, students expressed appreciation for the creative integration of mathematics and art.
	GeoGebra was found to be an effective tool for engaging students in mathematical explorations through artistic representations.
	Some students exhibited increased motivation and interest in mathematics due to the artistic nature of the task.
Recommendations for Practitioners	Educators should provide additional support materials and training for students using GeoGebra.
	Schools should consider improving access to technology in order to facilitate better learning experiences.
	Integrating function art into the curriculum can foster student engagement and interdisciplinary learning.
Recommendations for Researchers	Further studies should explore the long-term impact of function art on students' mathematical understanding.
	Comparative studies on different digital tools for creating function art could provide deeper insights into their effectiveness.
	Research on teacher perspectives and professional development for integrating function art into classrooms should be conducted.
Impact on Society	By demonstrating how function art can enhance mathematical learning and creativity, this study supports innovative educational approaches. It also highlights the need for better technological infrastructure in educational institutions.
Future Research	Future research should focus on expanding the study to different educational settings, examining the role of cultural influences in function art, and exploring the potential of functions in 3D in enhancing function-based artistic expressions.

Keywords	function art, challenges and opportunities, STEAM education, digital literacy, educational technology

INTRODUCTION

Science, Technology, Engineering, Arts, and Mathematics (STEAM) education helps students integrate knowledge from various disciplines to solve real-life problems (Mitchell & Forestieri, 2018). Project-based learning, inquiry-based learning, and problem-based learning are among the teaching approaches in STEAM education (Diego-Mantecon et al., 2021; Li et al., 2020). STEAM education helps students develop creativity, critical thinking, and innovation (Allina, 2018; Perignat & Katz-Buonincontro, 2019). For example, various studies report that STEAM education positively impacts student creativity (e.g., Aguilera & Ortiz-Revilla, 2021; Ozkan & Umdu Topsakal, 2021; Tran et al., 2021). Since creativity, innovation, and critical thinking are among the most valuable skills in the 21st century (Trilling & Fadel, 2009), STEAM education can support students in developing these skills. Thus, educators are increasingly interested in STEAM education (Li et al., 2020).

STEAM activities require the integration of at least two disciplines (Sanders, 2009). In our study, we integrated three disciplines: technology, art, and mathematics. We allowed the students to use GeoGebra, a free dynamic geometry software, to create artworks using graphs of mathematical functions. We selected functions because they are a fundamental topic in higher mathematics and are taught across various grade levels (Jurdak & El Mouhayar, 2014; Ronda, 2015).

Mastery of mathematical functions is essential for learning higher mathematics, particularly calculus (Oehrtman et al., 2008). In the Philippines, mathematical functions are a key component of the curriculum across junior and senior high school levels (Department of Education, 2016). However, teaching practices are often based on teaching mathematics in a less contextualized way (Benedicto & Andrade, 2022), which may limit students from developing skills such as creativity and critical thinking. This may compromise students' skill development needed to cope with demands of the 21st-century life.

While traditional mathematics teaching in the Philippines often lacks contextualization, few studies have examined how students respond to the challenges and opportunities of integrating mathematics and art through digital tools. This study aims to fill the gap by focusing on students' experiences in creating digital artwork. One such approach is graphing art, where students manually sketched artwork on graph paper and derive equations to represent the curves (Avila, 2013; Disher, 1995). Despite the potential of graphing art to illustrate the application of mathematics in the arts, it constrains students to simple functions because most functions are difficult to derive from graphs. In addition, it prevents students from utilizing dynamic interactive software such as GeoGebra to apply mathematics to art.

Exploring the combination of mathematics and the arts (Farris, 2021; Gamwell, 2016; Lähdesmäki & Fenyvesi, 2017), such as creating mathematical art in an educational context, serves as a dynamic tool for fostering students' understanding of interdisciplinary connections. Blending mathematical and artistic practices offers students a platform to view mathematics as a versatile language of expression (Fenyvesi et al., 2019). Arts integration in mathematics education promotes creative learning and deeper engagement with mathematical concepts, as research highlights its role in fostering phenomenon-based learning and enriching cultural and educational connections (Portaankorva-Koivisto & Havinga, 2019). Various forms of art, such as visual art, can be created using computer programs that incorporate variables and functions (Reas & Fry, 2007). This approach can also be applied in classroom settings. Research shows that integrating technologies to support students' application of mathematical functions in creating art enables them to link their learning with other disciplines (Bautista et al., 2025). This integration demonstrates how technology enhances the authenticity of mathematics learning in the context of the creation of arts and interdisciplinary exploration. As a result, Bautista et al. (2024a) proposed the *function art* approach, in which students use equations aided by GeoGebra, to draw curves in creating artworks. Function art is defined as "art constructions whose components include graphs or parts/segments of graphs of mathematical functions" (Bautista et al., 2024a). This approach provides students with a unique opportunity to integrate their creative expression with mathematical concepts (Bautista et al., 2024b). Although graphing art involves manual plotting, it can still be considered a form of function art, as it incorporates mathematical functions into the artistic process.

In our study, we explored the implementation of the function art approach to improve students' mathematics learning in selected schools in the Philippines. Specifically, we investigated the challenges and opportunities encountered by students during the implementation of the function art project. By examining these experiences, we aim to conduct an ongoing assessment of our implementation. We believe that findings from this study will inform practices for implementing function art and related STEAM activities in the Philippines.

THEORETICAL BACKGROUND

Valsiner (1987) extended Vygotsky's Zone of Proximal Development (ZPD) (Vygotsky, 1986) by introducing the Zone of Free Movement (ZFM) and the Zone of Promoted Action (ZPA) as frameworks for theorizing teaching and learning. Vygotsky's ZPD postulates that learning is most effective when it occurs within a specific range of cognitive development. Vygotsky argues that effective learning occurs when learners are challenged with tasks beyond their current understanding or ability but can achieve success with appropriate guidance and support.

The ZFM represents the space within which an individual can operate autonomously. This includes actions, thoughts, and behaviors that do not require external guidance. It encompasses factors such as students' access to areas and objects, and how they interact with those objects (Lightfoot, 1988, as cited in Blanton et al., 2005).

Conversely, the ZPA extends the concept of ZPD by emphasizing the significance of external assistance from "knowledgeable others." This assistance includes actions, thoughts, and behaviors that individuals can perform with support.

In creating function art, students are likely to encounter challenges and opportunities. Challenges may relate to their ZPD, while opportunities may align with their ZFM. Therefore, Valsiner's (1987) theory is highly relevant as the present study investigates the relationship between these challenges and opportunities. By examining this relationship, the study acknowledges that learning involves students navigating challenges and discovering solutions (i.e., the opportunities), reflecting the connection between ZFM and ZPA. Understanding this relationship may help researchers and teachers to facilitate learning more effectively.

RELATED LITERATURE

THE CONCEPT OF FUNCTION ART

The use of mathematical functions in art has been a research interest among educators since the 1990s. In graphing art (Avila, 2013; Disher, 1995), students typically sketch a design manually and then derive the equations to fit the curves, which restricts them to simple functions due to the complexity of formulating precise equations. To address these limitations, the function art approach incorporates technology like GeoGebra. In function art, students use equations and GeoGebra to create curves for the artwork. Unlike many DGS, GeoGebra supports two-way transition of representations, from algebra to geometry, and vice versa. This capability would give students a broader repertoire of methods and strategies in creating their artwork.

Figure 1 shows examples of function arts created by students using GeoGebra. The artworks are composed of graphs of functions (red), conics (green), line segments (blue), and images (black). The artwork on the left consists entirely of graphs of mathematical functions. The artwork in the center combines functions and conics (circle on the eyes and ellipse on the nose). The artwork on the right incorporates functions, conics, line segments, and images (gloves). These examples represent pure, organic, and hybrid function art, respectively (Bautista et al., 2024b).

In function art, students can select and manipulate mathematical functions to draw curves. While working on these functions, students not only deepen their understanding of mathematics, but also learn how to use technology. This interdisciplinary approach aligns with the principles of STEAM education, fostering learning experiences that integrate multiple domains of knowledge.

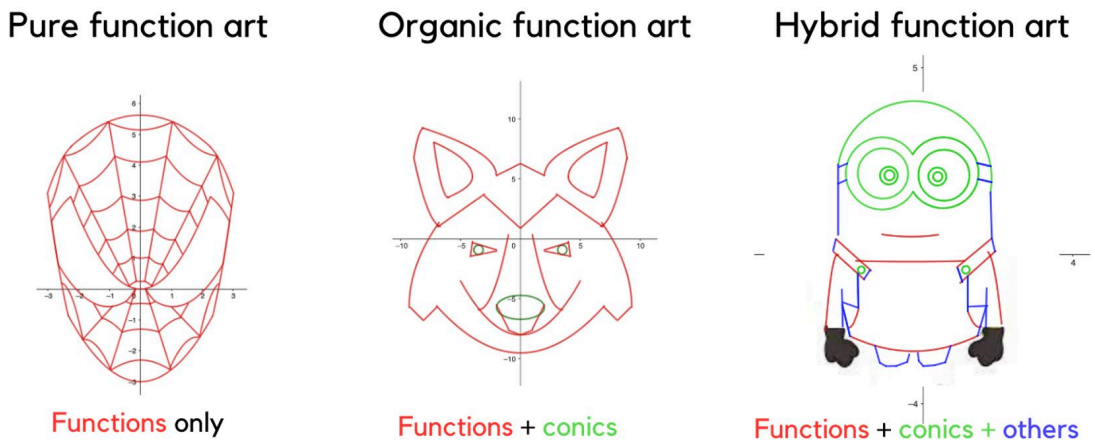

Figure 1. Types of function art. adopted from Bautista et al. (2024b)

Recent studies on the use of functions in creating artwork have capitalized on the capabilities of software applications to enable students to explore a broader range of functions and create more complex artwork. Examples include using function graphs in depicting letters (Rebholz, 2017), curve stitching (Bergthold, 2005), and allowing students to choose their artistic inspirations (Bautista et al., 2024a; Beigie, 2014). In addition to the studies previously discussed, there were other studies on the use of functions in creating artwork, such as those by Barry (2021), Aktümen and Avni (2016), and Pescaia (2016). However, these studies were less relevant to the current research as they did not involve high school students. Barry's (2021) study focused on self-exploration, Aktümen and Avni (2016) conducted their research with preservice teachers, and Pescaia's (2016) work was limited to proposing lesson plans.

The studies that involved students highlighted their outputs, motivation, and engagement. However, few studies have mentioned the challenges and opportunities associated with students' engagement in learning function art. Consequently, research like the present study, which focuses on challenges and opportunities, is critical to filling this gap.

Challenges in Functions and Opportunities in Function Art

Two studies have reported challenges and opportunities associated with function art. The first, by Disher (1995), found that students struggled with determining the domain of functions. Disher (1995) addressed these challenges by discussing different representations of domains, such as set and interval notations, and using the union and intersection symbols. This support provided the students with the opportunity to apply these concepts in creating their artwork.

The second study, by Avila (2013), highlighted the role of teacher support, such as conversion of representation in both directions (equations to graph and graph to equations), as an opportunity that enhanced students' learning in creating function art. In Avila's (2013) study, as a preparatory practice, students first practiced graphing by plotting a set of equations that formed specific artworks. For the main activity, students were given artwork and tasked with determining the equations of the curves.

The studies demonstrated that using functions to create artwork presents both challenges and opportunities for students. However, the insights from these studies cannot be generalized to contemporary contexts involving powerful dynamic geometry software. Earlier technologies often had limited graphing capabilities, restricting the complexity and interactivity of mathematical visualizations. As a result, students' experiences with older tools differ significantly from those using modern platforms like GeoGebra. This highlights the significance of the present study in providing insights relevant to today's educational environments.

Challenges in learning functions

Challenges in learning functions, even without applying them to create art, have been widely documented in the literature. These studies are relevant because functions are a core component of function art. A systematic literature review by Trujillo et al. (2023) identified several challenges students encountered when learning functions, including: (1) definition of functions, (2) interpretation or meaning of functions, (3) notation and expression, (4) graphical representations, and (5) management and characteristics of functions. The last three challenges are particularly relevant to function art and may also emerge as challenges to students in this context. In the following paragraphs, we discuss these challenges.

Function notation and expressions are challenging to students due to their multiple representations and meanings. For instance, Trujillo et al. (2023) found that students often confuse y and $f(x)$. This confusion leads students to the incorrect generalization that equations and functions are always equivalent. Students also face challenges with graphical representations, particularly when switching between algebraic and graphical representations. For example, students often fail to recognize that the points on a graph represent the infinite pairs of numbers that define the function.

Additionally, Trujillo et al. (2023) found that students struggle with understanding the management and characteristics of functions. For instance, some students do not consider constant function and non-continuous functions as functions.

Transformations of functions are another common challenge; for example, students often mistakenly interpret $y = f(x - h)$ as a translation of the graph of f to the left by h units for positive values of h (Borba & Confrey, 1996; Zazkis et al., 2003). Furthermore, the domain and range of functions have long been sources of challenges and misconceptions (P. Cho & Moore-Russo, 2014; P. Cho et al., 2017; Y. D. Cho, 2013).

Opportunities in function art

Despite the challenges in learning functions, function art may provide students opportunities to explore and apply functions, their transformations, and their properties while creating their artwork. Creating function art requires students to use the concept of domain and their notation to graph functions with finite lengths as shown in Figure 1. They would use the different transformations such as horizontal and vertical translations, horizontal and vertical scaling, and reflection across the x- and y-axes (Bautista et al., 2025). In GeoGebra, aside from functions, students can also use other mathematical objects such as ellipses and line segments (shown in Figure 2) and images (shown in Figure 1).

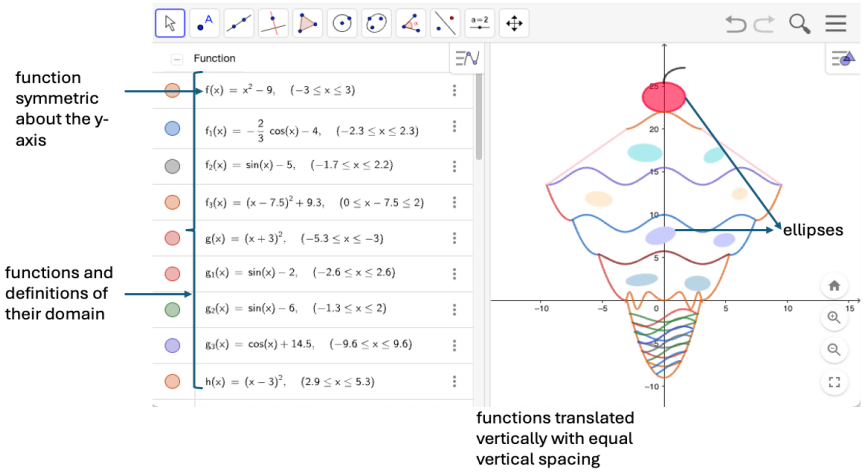

Figure 2. Sample student artwork highlighting symmetry and vertical translation

In summary, previous studies on function art have paid limited attention to the challenges and opportunities associated with student engagement. Conversely, Trujillo et al.'s (2023) review focused on challenges related to understanding functions rather than in the context of function art. Furthermore, these studies did not highlight the opportunities associated with learning mathematical functions in both theoretical and practical terms. These gaps highlight the need for a study that focuses on both the challenges and opportunities students face when creating function art. Thus, the present study aims to address these gaps by examining specific challenges students encounter and the potential of function art to enhance their understanding of mathematical functions.

METHODOLOGY

This study employed a qualitative single-case exploratory approach (Yin, 2018) to investigate the challenges and learning opportunities encountered by three classes of Grade 11 students as they create function art using GeoGebra. Although the participants came from different classes, they were treated as a single case because they experienced the same intervention, used the same instructional materials, and shared a similar educational and technological context. This case study design is suited to exploring in-depth the unique difficulties and contextual factors affecting students' experiences in a real-world educational setting. Through survey responses and thematic analysis, the study aims to generate insights that may inform the integration of function art into STEAM education frameworks.

PARTICIPANTS

This study was a part of the Function Art Project implemented by the first author from 2022 to 2025. The sample in this study was 111 Grade 11 students from a public high school in the northern part of the Philippines. These students belonged to a special class that had been screened through entrance examinations before they could enter the school. They were considered high-performing students compared to regular high school students in the Philippines.

Most participants were from middle-class families; 98% had computers and mobile phones at home, and all of those with devices were connected to the internet. This was not typical for schools in the Philippines, where only 58% had devices (Flores, 2021), and only 30% were connected to the internet (Santos, 2020). Therefore, the sample was not representative of the broader population of Grade 11 students in the country.

Although qualitative studies typically involve smaller samples, we decided to include all the students to capture a comprehensive range of experiences and challenges associated with function art. This larger sample size was maintained to support the exploratory nature of the study.

IMPLEMENTATION

The study started with a one-time 2.5-hour webinar on function art conducted by the first author and attended by the students and their mathematics teacher. The webinar covered the following topics:

1. Introduction to the graphical user interface of GeoGebra
2. Tutorial on how to plot graphs
3. Review of transformation of functions, including vertical and horizontal translations and scaling
4. A tutorial on restricting the domain of functions using GeoGebra
5. A demonstration of creating a simple artwork

Following the webinar, students were given one month to create their artwork. This extended time was provided to help them balance classroom commitments and avoid interference with their regular studies. During this period, students were encouraged to consult teachers for support as needed.

DATA COLLECTION AND ANALYSIS

Upon completing their artworks, students uploaded them to their GeoGebra accounts and then submitted the URL of their artwork via Google Forms. Additionally, they responded to survey questions about their experiences in creating artwork using mathematical functions. The students answered the following questions.

1. What challenges did you encounter when creating your artwork?
2. How did you solve these challenges?

The first question aimed to identify the challenges that students faced in creating their artwork, while the second explored the learning opportunities that arose as students addressed these challenges.

The data were analyzed using Braun and Clarke's (2006) thematic analysis framework, a qualitative research method for identifying, analyzing, and reporting patterns, or "themes," within a dataset (p. 79). The method provides a systematic yet flexible means for uncovering the underlying meanings and structures inherent in textual or visual data. Table 1 shows the phases of thematic analysis adopted from Braun and Clarke (2006).

Table 1. Phases of thematic analysis

PHASE	
1. Familiarizing with data	Transcribing data, reading and re-reading the data, noting down the initial ideas
2. Generating initial codes	Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code.
3. Searching for themes	Collating codes into potential themes, gathering all data relevant to each potential theme.
4. Reviewing themes	Checking if themes work in relation to coded extracts (Level 1) and the entire data set (Level 2), generating a thematic map of the analysis
5. Defining and naming themes	Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells, generating clear definitions and names for each theme.
6. Producing a report	The final opportunity for analysis. Selection of vivid compelling extract examples, final analysis of the selected extracts, relating back of the analysis to the research question and literature, producing scholarly report of the analysis

The phases in thematic analysis include familiarizing with the data, coding interesting features, searching, reviewing, and naming themes, and then producing a report (Braun & Clarke, 2006). To address researcher bias, two members of the research team independently reviewed and discussed the initial codes and themes to ensure intersubjective agreement. Additionally, the survey items were pilot-tested to 16 students outside the main sample to refine the clarity and appropriateness of the questions. Below, we detail how the thematic analysis was applied in the study.

In the familiarization phase, we thoroughly read all the students' survey responses, noted interesting patterns, and identified potential themes. Next, we proceeded to the coding phase where we generated short descriptive codes (Level 1) to summarize the responses. For example, a student response like "I encountered difficulties in limiting the functions, so I searched for a tutorial online," was initially coded as "restricting function domains" and then revised as "determining the function domain" (Level 2) to ensure a broader categorization. Similarly, a response stating, "I do not have a laptop,

that's why I had a hard time doing my work," was coded as "No laptop" (Level 1) and later revised as "Lack of device" (Level 2). The Level 2 codes were used for the third phase of analysis, which is searching for themes.

After coding all responses, 11 themes were identified, as illustrated in Column 1 of Table 2. After finalizing the themes, we reviewed them to ensure that Level 1 and Level 2 codes were appropriately categorized within each theme. During this review process, we recognized the need to consolidate "Function Selection," "Function Manipulation," and "Graphing and Visualization" into a single theme (see Review 1 column). The significant overlap among the codes within these themes prompted this decision. For instance, although at first, we categorized "Finding the right function for the tracing of the art" as "Function Selection," it also involves finding the correct parameter values (which can also be categorized as "Function Manipulation") and visualizing transformations (related to "Graphing and Visualization"). Therefore, such codes could fit into any of the three themes.

Table 2. Themes identified from Level 2 codes

Themes	Themes (Review 1)	Themes (Review 2)
Function Selection	Function Manipulation and Selection	Function Manipulation and Selection
Function Manipulation		
Graphing and Visualization		
Artistic Challenges	Artistic Challenges	Artistic Challenges (AC)
Time Constraint	Time Constraint	Time Constraint (TC)
Mathematical Knowledge	Insufficient Mathematical Knowledge	Insufficient Mathematical Knowledge (IM)
Tools and Software	Software Unfamiliarity	GeoGebra Unfamiliarity (GU)
Personal Challenges	Personal Challenges	Personal Challenges (PC)
Digital Challenges	Digital Challenges	Digital Challenges
Hardware Limitations	Hardware Limitations	
Other Challenges	Other Challenges	Other Challenges (OC)

Additionally, we categorized "Hardware Limitations" under "Digital Challenges" because it was difficult to separate software from hardware issues. For instance, software lags and crashes could stem from both software and hardware problems. Furthermore, we modified the category "Tools and Software" to "Software Unfamiliarity" to emphasize the unfamiliarity with software, considering that "Tools" could also refer to hardware in our context. However, we later refined this to "GeoGebra Unfamiliarity" as students primarily used GeoGebra, and any unfamiliarity with the software can be categorized as "Digital Challenges." These adjustments helped streamline our categorization process, which reduced the initial 11 themes to 8 (see Review 2 column) as shown in Table 2. The student solutions (opportunities) also went through thematic analysis.

After completing the first and second levels of coding, Level 2 codes were organized into themes. For instance, the code "determining the function domain" was categorized under the "Function Manipulation" theme because it involves manipulating the function to suit the curve on the artwork. Similarly, the code "Lack of device" was placed under the theme of "Hardware Limitations." After determining all the themes, we reviewed the answers again and ensured that they fit in each theme—

those that did not were categorized under the "Other Challenges" theme. We also followed the same process for Opportunities, but we will discuss its final themes in the Results section.

RESULTS

This study aimed to explore the challenges and opportunities associated with students' creation of function art. In this section, we present the findings based on themes drawn from the research question's keywords, namely, "challenges" and "opportunities."

CHALLENGES IN CREATING ARTWORKS

The data revealed a range of challenges faced by students in creating function art as summarized in Table 3. These challenges were categorized into four main themes: Mathematics, Art, Technology, and Other Challenges. Students' challenges were mainly the lack of knowledge of mathematical concepts, particularly mathematical functions, difficulty in selection of artworks, unfamiliarity with using GeoGebra, technological challenges, and personal challenges. We detailed these challenges below.

Table 3. Themes identified from students' challenges

CATEGORIES	THEMES	CODE	DESCRIPTION
Mathematics	Function Selection and Manipulation	CM1	Choosing the appropriate functions and changing its parameters to achieve the desired outcomes.
	Insufficient Math Knowledge	CM2	Understanding or familiarity with mathematical concepts, formulas, and procedures
Artistic Challenges	Artistic Challenges	CA1	Selecting the artwork and conceptualizing the desired outcome.
Technology Challenges	GeoGebra Unfamiliarity	CT1	Lack of experience or knowledge in using the GeoGebra application software
	Digital Challenges	CT2	Practical aspects of executing the artwork, including problems with hardware, software, or the internet.
Other Challenges	Time Constraint	CE1	Managing and completing the artwork within a limited timeframe.
	Personal Challenges	CE2	Individual limitations include skill levels, and personal preferences.
	Residual Challenges	CE3	Challenges do not explicitly fit into the main themes.

A three-character coding system was used to classify the challenges and opportunities. The first character indicated whether it was a challenge (C) or an opportunity (O) (see Table 3 and 4). The second character represented the categories: M for Mathematics, A for Art, T for Technology, and E for Other Challenges. The third character was a number identifying the sub-theme. For instance, CM1 refers to the first challenge in mathematics, and OT1 refers to the first opportunity in technology. Note that even if there was only one in a category, we still put 1 as the last character to be consistent with the number of characters in the coding scheme.

Mathematical challenges were divided into two categories: CM1 was about challenges related to functions, while CM2 encompassed other mathematical challenges. CM1 was the most popular challenge. Some students mentioned challenges such as finding the correct functions, restricting domains, and adjusting parameters to fit the desired curves. One student detailed her CM1 challenge in creating the artwork, stating:

"Dealing with this project wasn't all smooth since I have encountered a lot difficulties while finishing it. First, restricting was hard since I have to trial and error every function. Second, I have to find what type of function would work best in some of the parts in my artwork. Lastly, I am only limited in how much I can utilize the functions, so I was irrationally attempting other functions to see if they could assist me fill in the space that I need to draw."

Figure 3 illustrates the output of the previously quoted student. She primarily used quadratic functions and encountered challenges with the curves on the sides of the bear, as evidenced by the uneven curves. Additionally, there was a noticeable indentation in one of the curves on the fingers on the left arm and a protrusion in one of the curves on the fingers on the right arm.

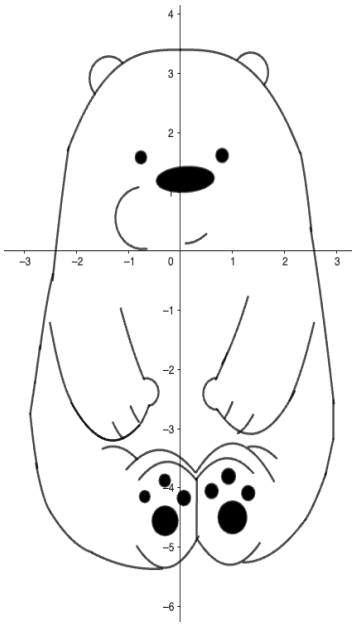

Figure 3. Sample output where student had challenges in using functions

In contrast, CM2 encompassed mathematical challenges unrelated to functions. Some examples were "cutting the circle" and "making a diagonal ellipse." While proper scaffolding could address the first challenge, the second one was beyond the scope of the curriculum.

Artistic Challenges (CA) mainly involved challenges in selecting and conceptualizing artwork. As one student candidly admitted:

"The difficulty that I encountered when creating my artwork was where to begin because I'm not really creative, therefore it's a little difficult for me to make my artwork. What I did to solve it was I tried putting different functions and see what I can do to it until I just found myself doing a butterfly artwork."

Another student experienced "art block" and spent too much time thinking about what artwork to create:

"I had an art block where in I could not think of an inspiration, I couldn't think of anything that I was not able to this project for a couple of days. And then I stumbled upon my old sketchpad that is full of drawings of Baymax."

Challenges in technology were divided into two subthemes: CT1 involved challenges in using GeoGebra, while CT2 were challenges related to other software and hardware. In CT1, some students

reported that the challenge they encountered was unfamiliarity with GeoGebra. However, one student managed to overcome this challenge by utilizing the help features and the frequently asked questions pages of the GeoGebra app and website:

> *"Manipulating and calibrating the app was really a challenge. Fortunately, they have a 'help' feature wherein I could ask questions or find questions similar to mine which have already been answered."*

CT2 encompassed all the other software, hardware, and internet challenges. Some of these included lack of hardware, laggy application software, outdated devices, and slow internet. Some students reported using mobile phones due to laptops not being available. One student expressed frustration over losing his work due to frequent application crashes:

> *"It's kinda challenging to make an artwork in mobile phone but as days pass I've been used to it, but there are times that I can't recover my works due to not saving it."*

Aside from the challenges above, students also struggled with Time Constraints (CE1), Personal Challenges (CE2), and Other Challenges (CE3). For time constraints, students complained about the tediousness of hiding the labels of objects, while some students admitted that they started their artwork only days before the due date, leaving insufficient time for refining the artwork (CE1). For CE2, a few students had difficulty keeping awake, while some struggled with prolonged screen exposure. One student also talked about procrastination (CE3):

> *"Procrastination is a huge problem, but I managed to create a system to overcome it and still create art."*

Our study identified various challenges faced by students in creating function art. We categorized them into Mathematics, Technology, Art, and Other challenges. Mathematical challenges encompassed difficulties with functions and other mathematical concepts. Technological challenges included issues with using GeoGebra and other software/hardware limitations. Artistic challenges involved selecting and conceptualizing artwork. Despite these challenges, the students demonstrated resourcefulness in overcoming them. Understanding these challenges may provide insights for educators to support better students in integrating mathematics and art.

Opportunities in Creating Artworks

The student opportunities to address their challenges also went through thematic analysis based on Braun and Clarke (2006). Here, we also used the coding process for student challenges. We used O as the first letter (O for opportunities) and M, A, T, and E, for Mathematical, Artistic, Technological, and other opportunities. Table 4 shows the final themes, categories, codes, and their definitions.

The opportunities in addressing the challenges in mathematics were divided into three categories: non-online research and learning (OM1), experimentation and exploration (OM2), and simplifying the problem and looking for alternative solutions (OM3). OM1 included reviewing notes and books as well as recalling mathematical concepts. For OM2 and OM3, although most of the answers classified under these themes were GeoGebra explorations, we classified them under mathematics because they used mathematical concepts in solving these problems. For example, "cutting" the function involves understanding the concept of domain.

Table 4. Themes identified from students' opportunities

CATEGORIES	THEMES	CODE	DESCRIPTION
Mathematics Opportunities	Research and Learning	OM1	Engaging in non-online research and reviewing course materials.
	Experimentation and Exploration	OM2	Trying different approaches to solving the problem
	Simplifying and Searching for Alternatives	OM3	Streamlining the approach and opting for straightforward solutions.
Artistic Opportunities	Finding Inspiration	OA1	Turning to personal interest, pop culture, and fandom
Technology Opportunities	Utilizing Online Resources	OT1	Using online platforms like Google, YouTube, and tutorial websites.
Other Opportunities	Persistence and Perseverance	OE1	Emphasizing perseverance, enduring challenges, and maintaining a persistent
	Asking for Help	OE2	Asking for assistance from peers, classmates, or family members.
	Residual Opportunities	OE3	Opportunities do not explicitly fit into the main themes.

Notably, many students sought alternatives, and simpler solutions to address the challenges. One student who used semi-circles and Circumcircular arcs in place of sine curves particularly said:

> *"One of the difficulties is I cannot exactly position the function at my desired shape. To solve this, I used other functions and tools that can be found in GeoGebra."*

Figure 4 illustrates this student's artwork. Thick curves represent graphs of functions, while dashed curves denote circles or circular arcs. As shown, many of the curves closely resemble perfect circular arcs, which was the reason why the student found it challenging to fit using function graphs.

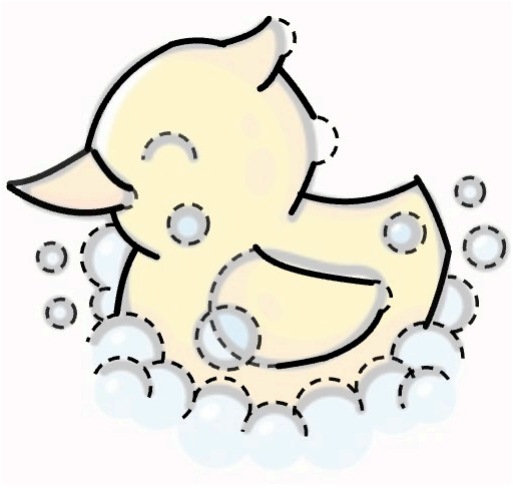

Figure 4. Sample output where curves are circular arcs

For OT1, students used "Google and YouTube" to search for solutions to challenges. Patience and Persistence (OE1) were also prominent in students' answers to solving the challenges that they encountered. They highlighted this opportunity to address challenges that were difficult to solve or things they had no control over. One student shared his solution when he could not find a way to "cut" the circle:

> *"I used the availability of resources online for me to know what function should I use, and I put time and effort also, Have patience."*

There were also students who used various methods in solving their challenges. Here is one example.

> *"I try to use the links provided by my teacher for using this Geogebra app, I also watched tutorials on Youtube on how to use this app, and I also asked my friends for help or asked questions about concepts that I didn't quite understand."*

Asking for Help (OE2) was also one of the opportunities that students encounter in addressing the challenges. Students mentioned asking for help from their classmates and friends. This provided students with an opportunity to help and collaborate with each other. However, none of them mentioned asking for help from their teachers. When we asked the teacher about this, she recalled that two students asked how to "cut the functions."

From the results above, students found various opportunities to address the challenges that they encountered. This included relearning and reviewing the mathematical concepts related to the problem, resorting to online resources, and being persistent.

DISCUSSION

In our study, students encountered various challenges in creating function art, including mathematical, technological, and artistic challenges as well as personal barriers. This implies that students need comprehensive support that addresses multiple aspects of learning if they are to learn successfully. This aligns with Valsiner's (1987) theory which calls for teachers to help learners to learn new knowledge, objects, and how to use such objects.

MATHEMATICAL CHALLENGES AND OPPORTUNITIES

The most common mathematical challenges that emerged in this study include selecting appropriate functions to approximate a curve and restricting the domains to "cut" the function graphs. These challenges likely stem from students' lack of understanding of the properties of functions. These findings align with those of Trujillo et al. (2023) which pointed out that one of the challenges students face consistently is switching between algebraic and graphical representations (p.6), which is precisely the skill needed to create function art. Additionally, understanding how to "cut" graphs involves grasping the concepts of domain and range, which have also been identified as challenging in several studies mentioned in the literature (P. Cho & Moore-Russo, 2014; P. Cho et al., 2017; Y. D. Cho, 2013).

One notable challenge that students face is "converting circles into functions," a task that requires manual computation. Since this is common to students, it indicates that they are not able to make connections between algebraic computations and the concept of function. This challenge offers an opportunity for teachers to provide scaffolding (Vygotsky, 1986). Specifically, teachers can explain the difference between circles and functions and why additional steps, such as dividing the circle into two semi-circles or several arcs, are necessary for the conversion. These questions and explanations fall within the Zone of Promoted Action (ZPA), where the teacher acts as a more knowledgeable other (Vygotsky, 1986) to guide students toward a deeper understanding of the relationship between circles and functions. This is possible because students have already learned the prerequisite skills,

such as radicals and solving quadratic equations, and thus, these tasks fall within their ZPD. As Blanton et al. (2005, p. 7) emphasize:

> *"Instructional efficacy is optimized when the relationship between the ZPA and ZPD is such that what is promoted (ZPA) lies within the individual's ability to achieve this (ZPD)."*

The challenges in function selection, domain restriction, and geometric conversion highlight critical areas where targeted instructional support can strengthen students' understanding of functions. By aligning teaching interventions with students' ZPD and using scaffolded guidance within their ZPA, educators can facilitate meaningful connections between mathematical concepts and practical applications in function art.

Technological Challenges and Opportunities

The most common technological challenges are unfamiliarity with GeoGebra and hardware and software problems. Given that unfamiliarity with GeoGebra was a common challenge, it may be beneficial for teachers to provide students with more exercises and guided practice using GeoGebra before assigning function art tasks. This highlights the need for teachers to be proficient in the GeoGebra software to be able to support the students by answering their questions and by providing tailored learning materials that target common difficulties. This could help students become more comfortable with the app and reduce technological challenges while doing the artwork. Conversely, hardware and software issues highlight the need for up-to-date devices to enable students to work effectively on function art.

Although most students reported having access to computers or mobile phones at home, many still experienced difficulties in using technology. Several students noted that their devices were outdated, which made running GeoGebra or accessing online materials difficult. Interestingly, despite the high percentage of reported device ownership, some students mentioned lacking access during key times—likely because the devices were shared within the family or used by others for work or study. These limitations suggest that access alone does not guarantee effective use of technology for learning, especially when dealing with resource-intensive tasks like function art.

The technological challenges identified in this study were not present in the literature on graphing art. Earlier studies by Disher (1995) and Avila (2013) mainly involved manual graph sketching, so technology was not a concern. Later studies also focused on the students' outputs and did not report such challenges. This is likely because they were conducted in schools where technology was readily available to students and that the students were familiar with it.

Other technological challenges, such as limited access to technology and the internet, mean that teachers implementing function art need to consider them and should provide technological support and alternatives so that students can create their artwork with minimal barriers. In Zone theory, by supporting students, teachers can help students move from their ZPD to their ZPA (Valsiner, 1987).

Artistic Challenges and Opportunities

The Artistic Challenges encountered by students often involve difficulty in deciding what artwork to create—an aspect that aligns with Valsiner's (1987) ZFM, which emphasizes that learner's autonomy in exploring within accessible resources and contexts. Some students reported experiencing "art block." To address these challenges, the teacher implementing function art may need to collaborate with other teachers, particularly art teachers, to support students. This approach not only aligns with the core tenets of Zone Theory but also with the principles of STEAM education (Fields & Kafai, 2023).

In summary, the challenges encountered by the students provided them with opportunities to look for solutions on their own. Some students reviewed their notes, some used the help feature of GeoGebra and the frequently asked questions on GeoGebra's website, and others looked for tutorials on

the internet. Interestingly, few students asked for the teacher's help. This suggests that students preferred to solve problems independently. The students' actions suggest that many challenges fell within their Zone of Proximal Development (ZPD), where they could overcome challenges with minimal external assistance. The fact that few students sought help from the teacher aligns with the idea that learners often operate within their ZFM, using accessible tools and resources to navigate their learning environment. This also suggests that providing comprehensive, easily accessible learning materials like tutorials and FAQs can effectively support student learning and foster greater independence.

The unique contribution of this paper is the identification of the challenges and opportunities students encounter in creating function art. Although there is rich literature about the challenges students face in learning functions, few studies have identified such challenges in the context of function art in particular, or the integration of mathematical functions and art in general. This provides a fresh perspective in this field and can be used by practitioners in implementing similar STEAM activities and designing lessons in mathematics, particularly on the transformation of functions.

In addition, while this paper focuses on function art, its insights may also apply to other educational contexts, particularly integrating technology, art, and mathematics in developing countries. Given the limitations in access to technology in these regions, similar challenges are likely to be encountered. Thus, this research informs the integration of function art into the curriculum and highlights critical considerations for the broader use of technology in mathematics education.

CONCLUSION

This study identified key challenges that students encountered, including difficulties in selecting appropriate functions, restricting domains, and dealing with limited access to technology. Despite these challenges, students were able to find opportunities for learning through persistence, experimentation, and collaboration with peers. The results suggest that function art, with the help of tools like GeoGebra, can support interdisciplinary learning and enhance students' resourcefulness. These insights may help educators and curriculum developers create more inclusive STEAM initiatives that effectively combine mathematics and art. By recognizing the specific areas where students struggle, educators can develop interventions to address these needs and create a more conducive learning environment. Encouraging collaborative learning and providing access to diverse online resources can empower students to navigate challenges more effectively and enhance their problem-solving skills.

This study focused on a qualitative case involving 111 Grade 11 students from a high-performing public school. Although we gained valuable insights from this study, it does not represent a broader population of Grade 11 students in the country. Factors such as academic performance, grade level, type of school (private vs. public), access to resources, etc., were not varied, which limits the generalizability of the findings.

In addition, this study was conducted on students with a relatively better access to technology which may not reflect the challenges and opportunities that students face in under-resourced schools. Future research should consider comparative studies with diverse samples to explore how these variables affect student challenges and opportunities. Such research could offer a more comprehensive understanding of integrating function art into diverse educational contexts.

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