Advances in Social Sciences Research Journal – Vol. 11, No. 1
Publication Date: January 25, 2024
DOI:10.14738/assrj.111.16349.
Baez, R., Sanchez, H., & Pllana, D. (2024). Creativity in High School Through Drawing with Polynomials. Advances in Social Sciences Research Journal, 11(1). 318-332.

Creativity in High School Through Drawing with Polynomials

Rudy Baez
Jose Marti STEM Academy High School Union City NJ

Henry Sanchez
Jose Marti STEM Academy High School Union City NJ

Duli Pllana
Jose Marti STEM Academy High School Union City NJ

ABSTRACT

High school math projects center on solving real-world examples in a wide variety of situations that require a creative skill set. Creativity in high school mathematics takes place in a subtle form. In contrast, creativity presents itself conspicuously in art. Therefore, this paper will explore the utilization of polynomial equations in drawing various figures as part of algebra class projects. Additionally, these projects incorporate integrated digital tools in mathematics. The paper will analyze three algebraic projects: the first project involves drawing a bird, the second project focuses on drawing a butterfly, and the third project entails drawing a bat using polynomial equations with the technological tool Desmos. All three projects are products of student work that encompass figures requiring up to forty polynomial equations. The students' impressive work demonstrates the power of mathematics in pushing the boundaries of other subjects. As digital technology becomes increasingly integral, mathematical tools are positioned as universal tools for the future and are poised to rival artists in producing visual art. This raises the intriguing question: can a mathematician create better art with mathematical equations through digital technology than an artist?

Keywords: The bird, butterfly, bat, projects, drawing, creativity, math, art, the teacher, students, group work

INTRODUCTION

Generally, the presence of creativity in high schools within any school district is limited, whereas the domain of art offers a broader scope for creative expression. Integrating mathematics with artistic elements during high school projects could lead to the creation of innovative artworks. For instance, a project assigned to an algebra class could involve drawing a figure—any image or photography that captures the students' interest—by employing polynomial and parametric equations and algebraic strategies taught in their classes. Students could showcase their work using various versions of PowerPoint or Google Slides.

The cooperative nature of PowerPoint projects is thus motivating and provides a stimulating environment for students (Apple and Kikuchi, 2007). Additionally, students could utilize technological tools; while various software options are available, Desmos stands out as an easyto-use and effective choice. Desmos is (free access) faster at graphing, thus providing immediate feedback to the students who can see the function change in real-time as they modify parameters (King, 2017). By modeling a chosen image and scrutinizing it through the lens of mathematical equations, students can creatively bridge the realms of math and art—transforming mathematical projects into artistic expressions—using the technological prowess of Desmos.

Mathematics and art share a profound relationship, particularly in the exploration of patterns and the graphical interpretation of mathematical examples and concepts. The relationship between math and art is a complex and multifaceted one, but there is evidence to suggest that mathematical principles play a fundamental role in creative expression (Ekbote, 2023). Experimenting with diverse mathematical equations within the Cartesian system produces a range of graphs, each showcasing distinct and often unpredictable shapes. Through the utilization of digital technology, students can combine various polynomials through trial and error, thereby giving rise to imaginative and unforeseen shapes.

Digital technology boasts extensive applications, particularly when Internet access is considered. Integrating technology into mathematics education facilitates collaboration among teachers and enables both students and educators to expand their knowledge base. For instance, teachers can discover various activities aligned with their topics, employing them to reinforce their understanding. Teachers can assign homework and projects through websites, fostering communication with students to address any lingering questions.

Students can leverage a range of applications such as Desmos, Geogebra, Wolfram Calculator, and various online calculators as mathematical tools to solve problems and graph functions spanning linear, quadratic, cubic, rational, exponential, logarithmic, trigonometric, parametric, piecewise-defined, mathematical animations, and more. Desmos is proficient in foundational computations, and can also be adapted for various graph-related and non-graph-related functionalities. These encompass calculating partial sums, estimating function roots, determining definite integral values, and even finding the greatest common factors within a list of integers (Math Valute, n.d.)

Students from a technology-focused urban high school in New Jersey utilized the technological tool app, Desmos, to successfully complete a project within their Algebra 2 classes. This approach facilitates the development of student understanding of the connections between elements, not simply the application of steps and formulas (Ives, n.d.). The project entailed creating a figure from scratch using familiar mathematical equations. Students opted for various figures including butterflies, bugs, Mickey Mouse, bats, birds, and more. The focus of this paper lies in the examination of three innovative projects from distinct groups, involving the illustration of a bird, a butterfly, and a bat using polynomial equations presented in the form of piecewise functions and equations.

METHOD

The teacher assigned a group project to the students, tasking them with drawing figures using mathematical equations through Desmos. They were required to select a figure from a real-world example, analyze its key characteristics, and subsequently render it utilizing polynomial functions. The underlying concept aimed to manifest the creative essence of mathematics

URL: http://dx.doi.org/10.14738/assrj.111.16349

through the medium of art. It requires looking at things from multiple angles and being willing to explore new possibilities (Ammy, 2023).

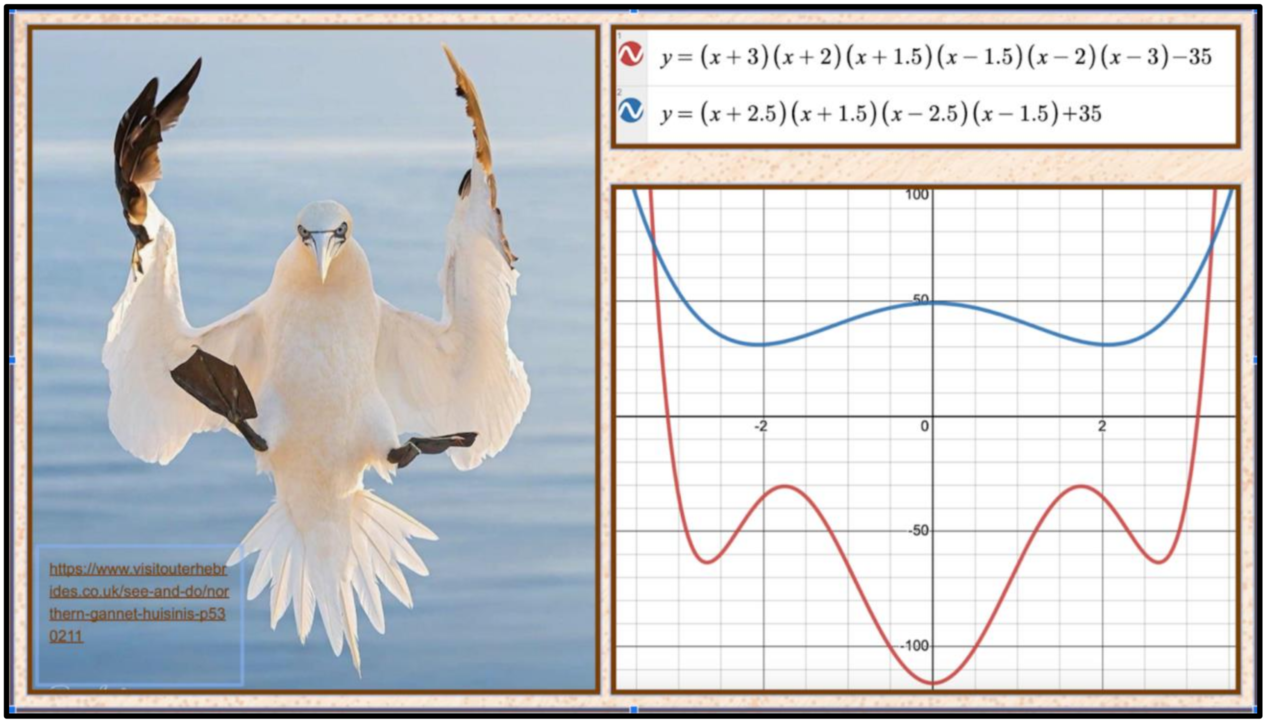

Figure 1: The figure on the left side depicts a bird that is symmetric with respect to the y axis and the right side presents polynomial functions describing the shape of the bird (Outer Hebrides, n.d) - Students work (project The Bird – google slide 3).

For instance, the teacher initiated the process with Figure 1. Displaying a real-world entity on the left side, the teacher generated two polynomial functions (using Desmos) on the right to depict the figure. The subsequent step involved assigning a group of students the task of expanding upon Figure 1. Their objective was to introduce additional polynomial functions until the figure on the right mirrored the one on the left. The students were guided to present a minimum of four distinct slides, each featuring equations. Furthermore, each slide was to incorporate a greater number of equations than the previous one, progressively converging the figure to closely resemble the real-world counterpart. Ultimately, the selected group—the one that demonstrated the most exemplary performance, successfully completed the project. They accomplished the task by employing 39 polynomial equations to bring to life Figures 2 and 3.

The mathematics teacher assigned a project to students, dividing them into groups of four. Their task was to employ polynomial functions combined with well-defined piecewise functions, facilitated through the digital prowess of Desmos, to artistically depict the shape of a bird. The illustration presented in Figure 1 encompassed a real-world example, depicting the bird on the left side, while juxtaposing it with two polynomial equations on the right side—these equations served as illustrative examples to guide students in their own projects. It is worth noting, however, that each individual project was expected to be wholly distinctive—a product of creative endeavor, never witnessed before.

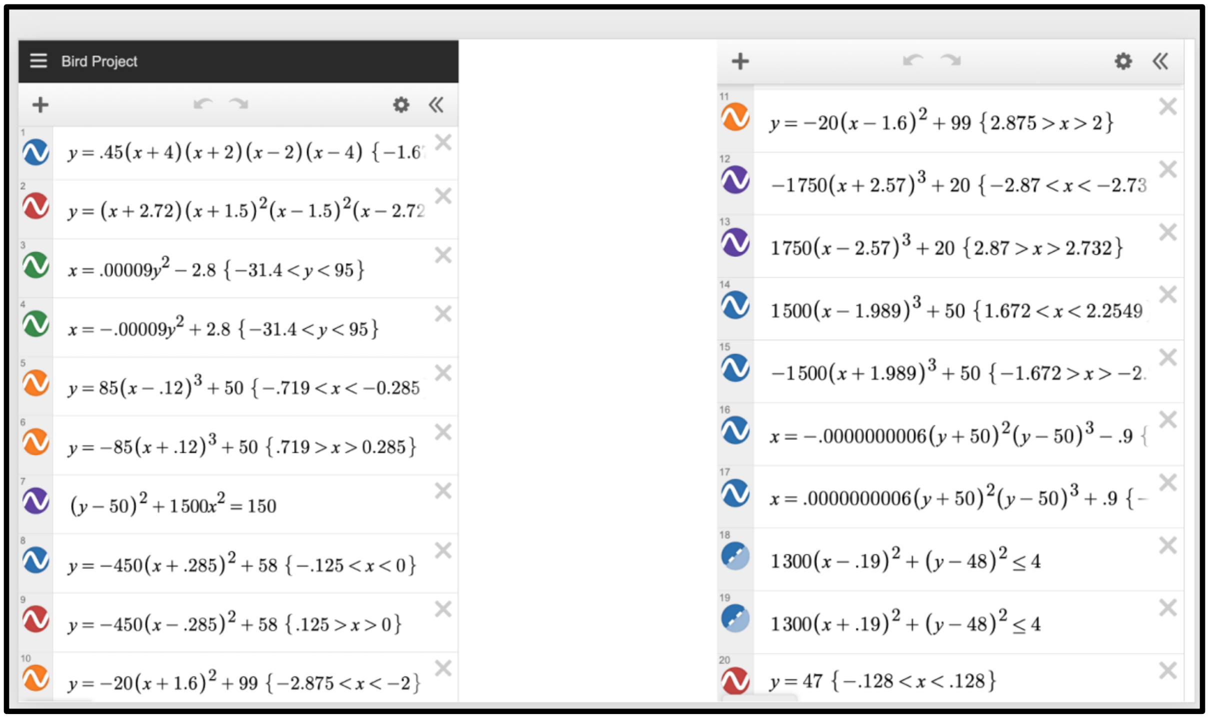

Figure 2: Represents 20 - polynomial equations (first part) in the DESMOS that describes the shape of the bird - Students work (project The Bird – google slides 9).

Desmos stands out as a remarkable tool, shedding light on mathematical functions while also offering assistance in various interdisciplinary fields that necessitate visual interpretation of data, functions, or general outcomes. Desmos emerges as a potent mathematical instrument that effortlessly blends with the realm of artistic expression. According to (Alfonso and Franco, 2021), in the educational context, there have been concerted efforts to establish a dialogue between the domains of art and mathematics.

Desmos encourages students to practice their math skills and explore mathematical concepts by utilizing creative tools (Abacus, 2022). Upon analyzing the polynomial equations presented in Figure 2 and Figure 3, it becomes evident that students employed various strategies while crafting lines and curves. On multiple occasions, students incorporated scaling factors and leading coefficients into the polynomial equations. This allowed them to explore the intricate relationship between these factors and the resulting vertical or horizontal stretches and compressions of the functions. Consequently, they were empowered to manipulate the directions of the lines and curves in accordance with their intentions.

Some students requested the option to select various real-world living things as models, as they felt more at ease modifying specific figures. The teacher granted permission for students to choose a real-world subject of their preference and portray it using polynomial functions or equations, employing mathematical tools for visualization. Stein and Wanstreet (2003) concluded that the element of choice plays a critical role in adult learners' education, facilitating the learning process. The act of making choices becomes intertwined with learning style and individual preferences, a principle that holds true for younger learners as well. The resulting projects surpassed all expectations; students crafted diverse figures including bats, butterflies, birds, bugs, and more. Through collaborative learning in face-to-face classes, they elevated their learning experience, a methodology equally applicable to online classes.

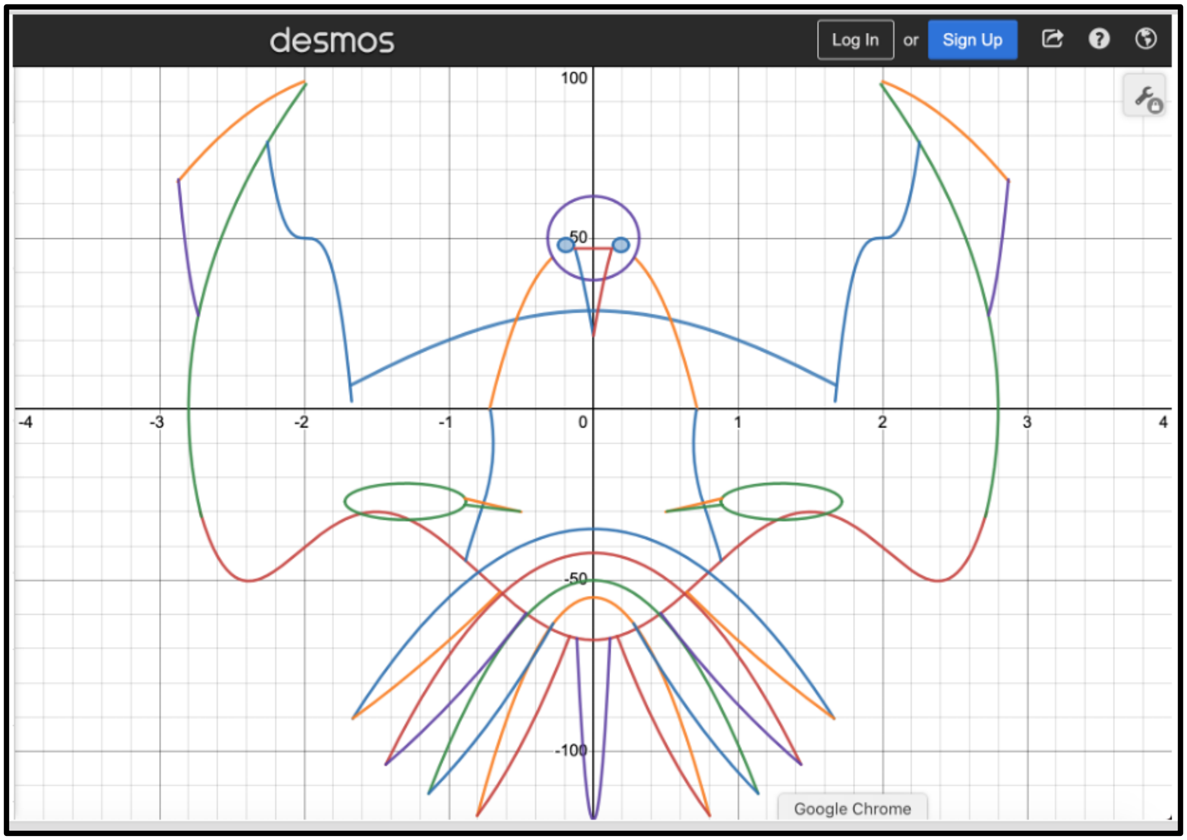

Figure 3: The complete figure of the bird is performed by 39 polynomial equations and piecewise well-defined functions through DESMOS - at the technology-focused, urban high school in New Jersey - Students work (project The Bird – google slide 18).

The Bird Project involved a designated group of students from an urban, technology-focused high school in New Jersey. This group successfully executed the project showcased in Figures 2, 3, and 4. The assignment tasked students with depicting a bird through polynomial functions, employing restricted domains and ranges—a practical application of piecewise well-defined functions. Detailed within Figures 2 and 4 are approximately 39 polynomial equations that intricately define the captivating artwork presented in Figure 3.

Employing collaborative efforts to solve mathematical problems offers a profound approach to engage with the learning process. In this instance, students harnessed the power of teamwork to gain a deeper comprehension of applying polynomial functions in real-world scenarios. Their collective effort culminated in a remarkable masterpiece.

Working within groups while completing a project allows students to cultivate teamwork skills. Teamwork holds a pivotal role in collaborative learning, facilitating the development and exchange of new ideas, encouraging participation in various discussion activities, idea testing, fostering creativity, and advancing critical thinking. Collaborative learning necessitates certain criteria for fulfillment, such as establishing a welcoming environment in which students can freely express their thoughts. Once the preliminary conditions are met, collaborative learning comes into play.

By learning collectively, students can enrich their educational experiences. This approach enables them to scrutinize their ideas for coherence and benefit from feedback provided by peers, validating their work. Successful teamwork yields exceptional outcomes and generates innovative creations, as depicted in Figures 3, 6, and 9. Moreover, the teacher tasked them with composing a paragraph reflecting on their acquired knowledge in the final slide. This concluding slide prompts students to introspect about their work and catalyzes transformative learning.

The Bird Project involved a designated group of students from a technology-focused urban high school in New Jersey. This group successfully completed the project showcased in Figures 2, 3, and 4. The assignment tasked students with creating an illustration of a bird using polynomial functions within restricted domains and ranges—an application of piecewise well-defined functions. Figures 2 and 4 provide detailed explanations of approximately 34 polynomial equations and 5 parametric equations, which collectively describe the beautiful artwork presented in Figure 3.

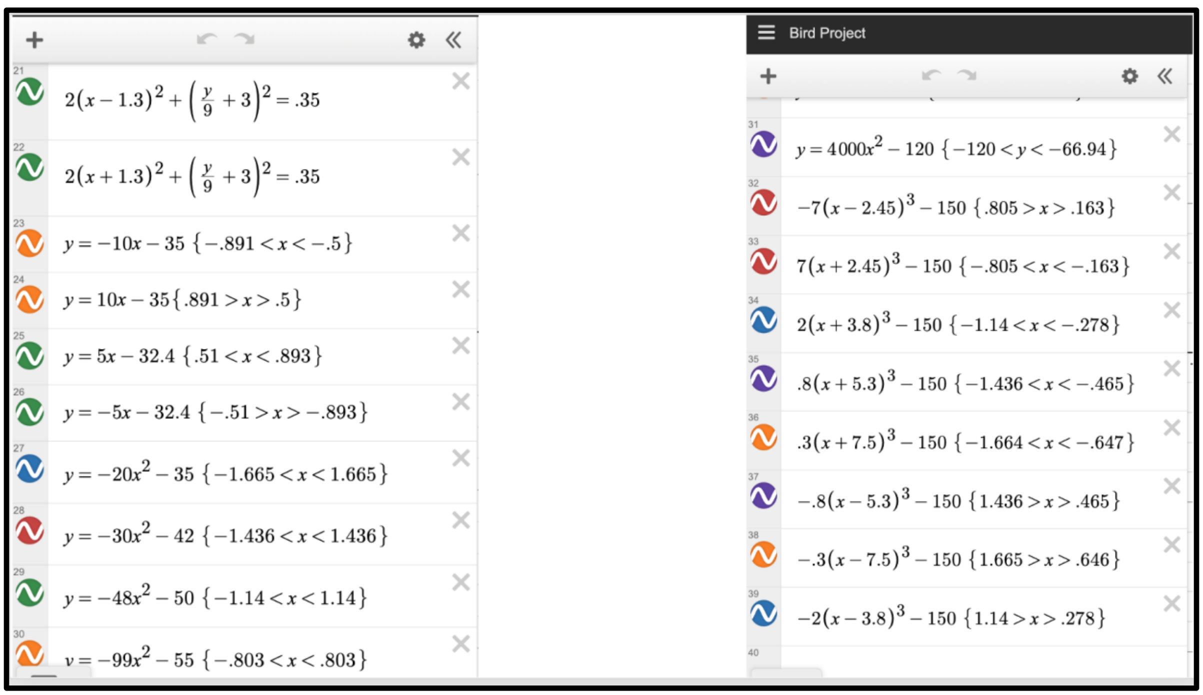

Figure 4: Represents 19 - polynomial equations (second part) in the DESMOS that describes the shape of the bird - Students work (project The Bird – google slide 15).

Utilizing group work to solve mathematical problems offers an excellent method for delving deeper into the learning process. Through teamwork, students gained a better understanding of applying polynomial functions in real-world contexts, resulting in a remarkable masterpiece. In the Bird Project, the students' team harnessed their intuition and creative ideas to complete their projects. Individuals with strong instincts often elevate what is presented to them beyond its original form (Jakes, 2014, p.32). The student group initiated the project with just two equations. However, they went on to generate an additional thirty-seven polynomial equations or functions, resulting in the exquisite artwork depicted in Figure 3. People with great instinct always transform what they are given to more than what it was when presented to them (Jakes, 2014, p.25). The beauty of the resulting drawing emerged unexpectedly, rivaling the craftsmanship of a fine piece of art. The bird figure adheres to the principles of artistic design, exhibiting both symmetry and balance. The wings of the figure bear a striking resemblance to those of an actual living bird (Figure 1 - left). Additionally, the tail subtly signifies the number 9, which holds connotations of wisdom and experience in numerology. While this connection might be coincidental, the elements of creativity were undoubtedly at play—elevating the students' work to a higher echelon.

Furthermore, students effectively utilized equations for circles and ellipses, giving them the ability to adjust the centers, radii, and axes of symmetry based on their design. Through these activities, students gained practical experience in applying mathematical polynomial equations in diverse real-world contexts.

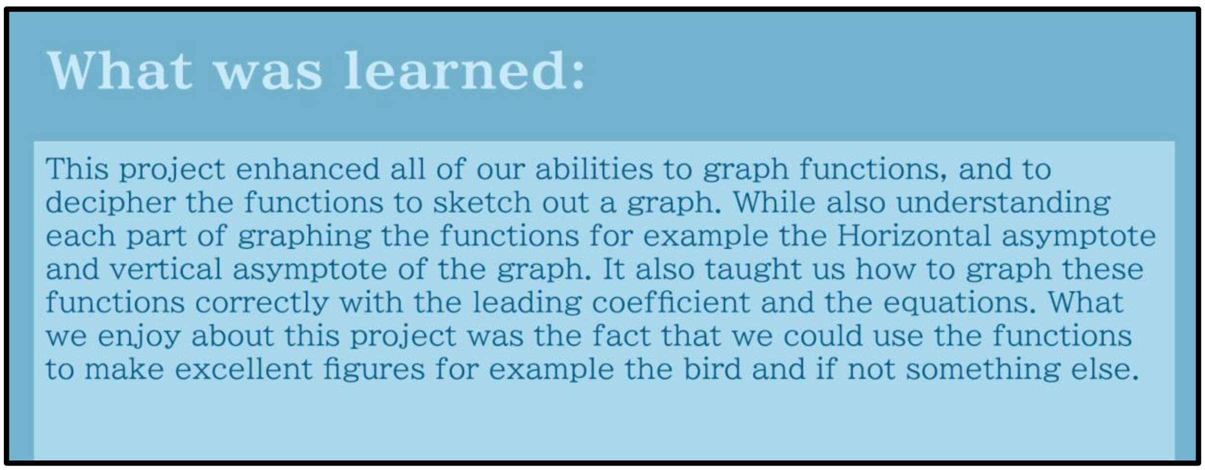

Figure 5: Students' reflection on the work - Drawing the bird with polynomial functions. Students applied mathematical strategies and techniques that they have learned in algebra 2 - Students work (project The Bird – google slide 20).

Equations 7, 18, 19, 21, and 22 are parametric (transcendental) equations, while the remaining equations in Figure 2 and Figure 4 are polynomial functions, satisfying the criteria of functions. Among these, equations 7, 18, and 19 depict circles, while equations 21 and 22 illustrate ellipses. It's important to note that every function can also be represented as an equation, but not every equation necessarily represents a function. The head and eyes of the bird are sketched using parametric equations describing circles, while the feet of the bird are delineated using parametric equations representing ellipses. Additionally, the piecewise functions in the drawing are well-defined and segmented, often linear in nature. Furthermore, both lines and curves within the artwork are characterized by polynomial functions, ranging from linear (degree one) to higher degrees.

Students demonstrated a keen focus on the figure's symmetry. Human preference for symmetry and regularity is a well-known phenomenon (Bertamini et al., 2019). From an artistic perspective, the bird figure exhibits symmetry with respect to the y-axis. Moreover, symmetrical curves are characterized by a pair of equations that are nearly identical, differing primarily in their signs. These sign differences cause the figure's shapes to mirror one another in opposite directions along the x-axis. While the students may not have explicitly discussed symmetry in the last paragraph, their work practically incorporated symmetrical elements throughout the project completion process.

Figure 5 encapsulates the students' reflections on their work. The students highlighted crucial elements of their project that underscored the influence of the leading coefficient and equations in reshaping the curves, ultimately influencing the bird's form. Notably, they mentioned the concept of a vertical asymptote, although it's important to clarify that this statement is inaccurate since polynomial functions do not possess asymptotes. While the teacher was cognizant of this error, they refrained from intervening, as creativity encompasses the freedom of self-expression. Mistakes, as recognized by Creative Fabrica (n.d.), serve as catalysts for thinking and growth. These errors are integral components of education, fostering the enhancement of students' skills. Excessive restrictions on students' work can stifle creativity, as their focus becomes confined to adhering to rules. This can lead to a suppression of their creative capacities, compelling them to seek only a predetermined solution. This is why the teacher opted not to burden them with numerous constraints, allowing them to explore diverse solutions that lie outside the conventional framework.

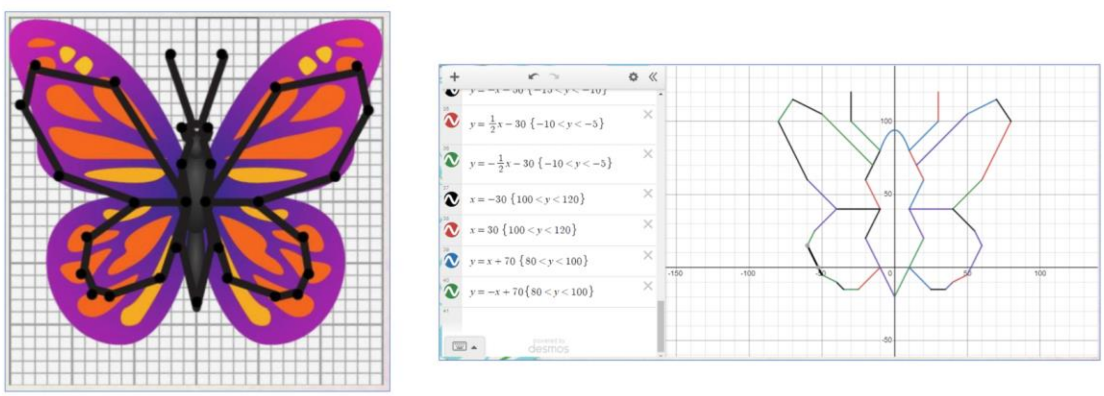

Figure 6: The complete figure of the butterfly is performed by 40 polynomial equations and piecewise well-defined functions through DESMOS -at the technology-focused, urban high school in New Jersey - Students work (project The Butterfly – google slides 1 and 10).

The Butterfly Project involved the creation of numerous exquisite and creative works. However, for the purpose of this writing, the focus is limited to just three selected projects. Among them, one group opted to center their project around a butterfly. Their approach involved working exclusively with simple linear equations, alongside a sole quadratic equation, all of which were characterized by piecewise well-defined functions.

Remarkably, even with their utilization of straightforward linear equations, their artistic endeavor culminated in a captivating depiction of a butterfly. This achievement underscores the effectiveness of simplicity as a powerful tool for elucidating complex problems through accessible language and clear visualizations.

Figure 6 was brought to life by students through the application of a single quadratic equation, while the remainder consisted of linear equations (a total of 39 piecewise well-defined linear equations). The spectrum of linear equations employed encompassed variations in leading coefficients, positive and negative slopes, horizontal slopes, undefined slopes, reflections over the y-axis, and incorporation of piecewise well-defined functions. Upon a casual observation of Figure 6, an impression emerges that the figure is composed of multiple segments, each governed by distinct polynomial equations. New research shows how going with our gut instincts can help guide us to faster, more accurate decisions (Minds at Work, 2016). However, it's important to note that intuition may occasionally lead us astray, as in the case of Figure 6. Despite the intuitive perception of a smaller number of components, the drawing actually comprises 40 equations, a quantity significantly greater than what intuition initially perceives.

Figure 6, displayed on the left side, is characterized by simplicity that encapsulates both beauty and uniqueness. The linear equations that define this figure typically form part of the introductory chapters of Algebra 2 and are explored further in Algebra 1. The elegant depiction of the butterfly is rendered through simple polynomial functions that encapsulate all pertinent intricacies. By exhibiting symmetry with respect to the y-axis and embodying elements of the golden mean, the figure exudes a striking beauty.

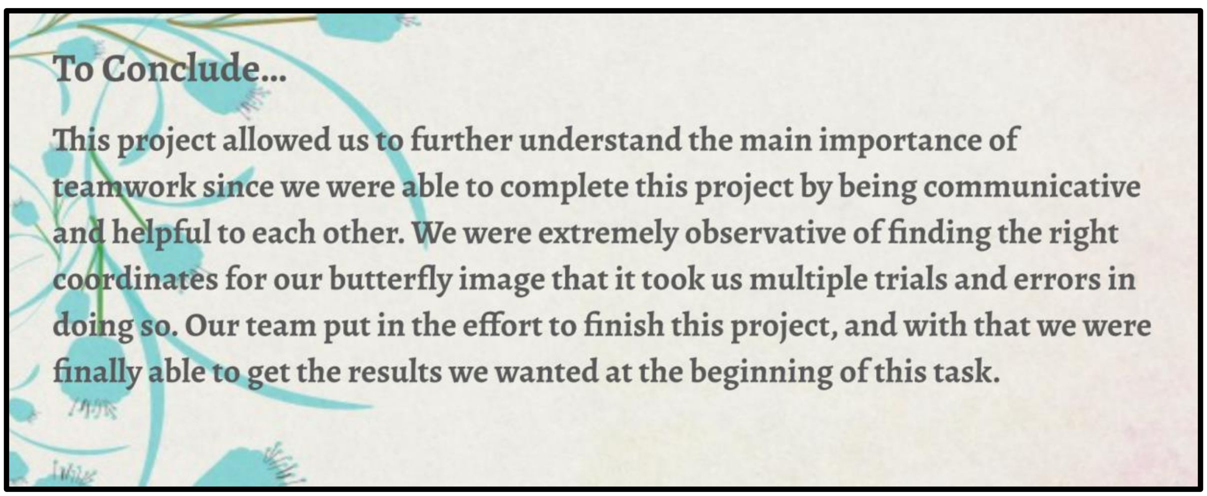

Figure 7: Students' reflection on their work - Drawing the butterfly with polynomial functions. Students applied the mathematical strategies and techniques that they have learned in algebra - Students work (project The Butterfly – google slide 11).

In contrast, another student group undertook the creation of the butterfly project. Notably, their project diverged significantly from the one featured in Figure 6. Each student group's project showcased individuality, a testament to their ability to fuse creativity with instinct, emotional intelligence, and intellect. Consequently, the project depicted in Figure 6 remains unparalleled in its uniqueness. Students envisioned the figure they were tasked to create within the project, yet they remained uncertain about the specific polynomial equations or functions that would yield the closely desired image. Through multiple trials, they embarked on a journey of trial and error to uncover the figure. The trial-and-error method is a problem-solving method where multiple attempts are made to get to a final solution (eduTinker, 2022). The ultimate solution doesn't necessarily foretell the precise path to completing the project. Students encapsulated their learning journey from the project within a paragraph featured in Figure 7, their final slide. This concluding paragraph serves to encapsulate their entire project experience, offering insight into their learning process. Polya emphasizes the significance of retrospection, asserting that valuable insights can be derived by reviewing and evaluating one's work, analyzing both successful and unsuccessful aspects (Polya, n.d.).

Through reflection, students engage in a process that encourages them to consider the completion of the project in its entirety. It fosters the application of metacognitive practices, enabling learners to become attuned to their strengths and weaknesses as writers, readers, test-takers, group participants, and more (Chick, 2013). In essence, the act of composing a paragraph about their projects empowers students to conduct a comprehensive review of their learning journey. The Bat Project serves as a testament to how high school-level mathematical concepts and strategies possess remarkable efficacy in tackling a diverse array of real-world examples. The application of mathematical concepts in practical scenarios necessitates insightful vision and strategic thinking. Visionaries, in particular, often harbor a creative facet within their personality (Huszczo, 2009, p.191). Figure 8 eloquently showcases the students' creativity as they skillfully employ mathematical tools, specifically polynomial functions, to render a depiction of a bat. The collaborative dynamics of the classroom foster a shared process of discovery between both teachers and students (Wentworth & Davis, 2002).

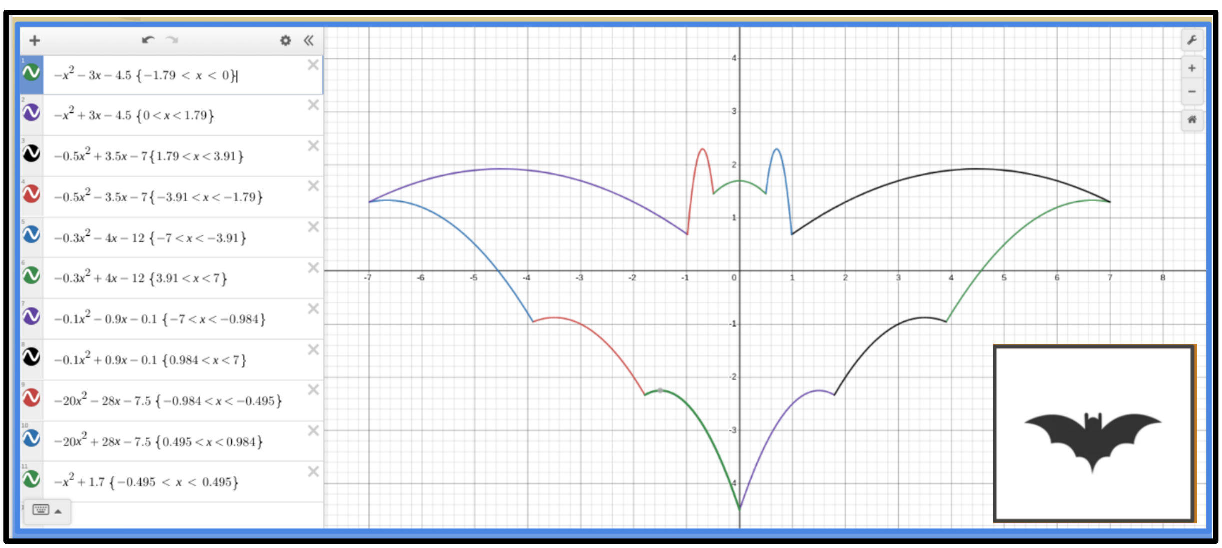

Figure 8: Students work on Project # 3, Drawing with polynomial functions and piecewise well-defined functions. (Students work in algebra 2 - class, at the technology-focused, urban high school in New Jersey) - Students work (project The Bat– google slides 2 and 6).

This project exemplifies the original work of students from a technology-focused urban high school in New Jersey. Remarkably, the students harnessed quadratic functions exclusively to draw the bat, as articulated in Figure 8. Their portrayal is ingeniously brought to life through a mere twelve quadratic equations (functions).

Figure 9 provides an intricate description of the students' work, elucidating the comprehensive process of project completion. Drawing from their reflections, students executed the project using a multitude of strategies and approaches that fostered a deeper comprehension of the subject matter. The diversity in methods highlights the versatility of tackling this project while depicting the art figure, in this case, the bat.

Effective teamwork is intricately intertwined with engagement, productivity, creativity, and overall satisfaction (DEAKUINCo, 2016). This particular group of students charted a distinctive path in illustrating the bat. Their fervent participation throughout the project culminated in a creative masterpiece that impeccably met the teacher's expectations for project outcomes.

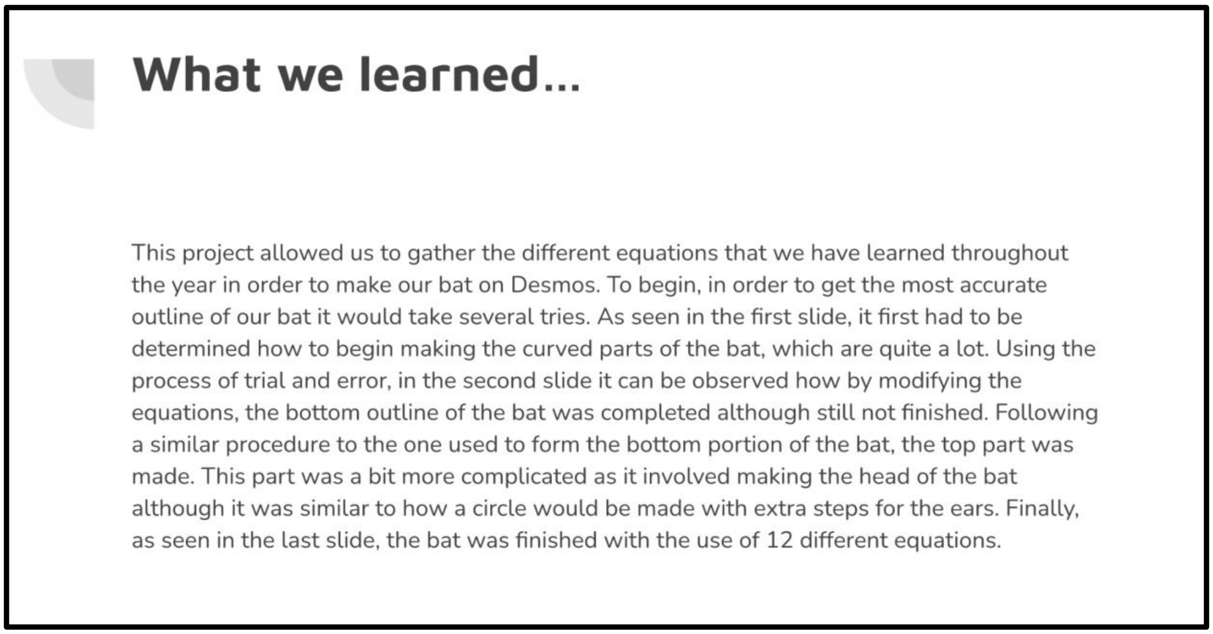

Figure 9: Students work on Project # 3, Reflection on drawing with polynomial functions and piecewise well-defined functions. (At the technology-focused, urban high school in New Jersey - students work in Algebra 2) - Students work (project The Bat– google slide 7).

RESULTS

Based on observations from group projects in Algebra 2, focusing on drawing using polynomial equations (functions), this study yields several key findings:

- Students effectively channeled their creativity to illustrate real-life subjects using polynomial equations.
- Assigning group projects prompted students to innovate and devise creative solutions.
- The question emerges: can mathematicians use math equations to create art that rivals traditional artists in the near future?
- Students recognized the value of teamwork in devising novel approaches towards desired solutions.
- The most prevalent problem-solving method employed by students was trial and error in real-world projects.
- Students tackled the task without a predetermined number of equations; instead, they concentrated on polynomial equations that approximated the intended shape.

- Most often, students utilized polynomial functions, occasionally supplementing them with parametric (transcendental) equations.
- Collaborative work among students fostered the application of creative elements within the projects.

These outcomes are grounded in the projects completed by students in the Algebra 2 class of a technology-focused urban high school in New Jersey. The results are an amalgamation of visual composition within the projects, the implementation of polynomial equations, and the insights offered through students' reflections in the final paragraphs of each project.

DISCUSSION

Three student group projects exhibit a fusion of creativity and problem-solving, showcasing the integration of mathematics and art to address real-world challenges. Students then learn to apply creative thinking and innovative methods in the development of projects in a way that addresses specific needs during the design phase (Sun and Kim, 2022).

Central to all these projects is the objective of constructing the most suitable drawing figure through the utilization of polynomial equations, closely resembling real-world entities according to Sun and Kim (2022). While the approximate solutions were discernible, the path taken to arrive at them defied precise prediction. Consequently, the solutions for these real-world instances emerged as unforeseen, novel, and creative solutions.

While the projects were not unfamiliar to the mathematical community, their content remained novel for the students. The teacher deliberately crafted scenarios that presented problems or situations, fully aware that no single answer or solution exists (Edutopia, 2007). It wasn't a matter of finding quick answers; rather, students invested significant time in developing satisfactory solutions. The project had a designated time frame of four weeks, aligning with the conditions of project-based learning. This timeline, from project inception to completion, was intentionally set to foster a comprehensive learning experience. The teacher's role as a facilitator encompassed several key responsibilities: providing clear project instructions, organizing student group work, aligning instructions with student interests, overseeing project originality, and offering guidance for ideas. The teacher's approach should involve assigning students to small groups, enabling collaborative efforts. Such teamwork not only enhances engagement but also cultivates a sense of responsibility among students, both to one another and to the project's completion (Teach Though Staff, 2013).

Moreover, teachers should take into consideration students' interests when selecting project topics. Rather than constraining them to a singular topic, educators should grant them the freedom to explore diverse subject matter. Imposing specific topics limits students' capacity for creativity and inhibits their ability to focus on content that resonates with their lives (Teach Though Staff, 2013). Additionally, teachers must maintain vigilance to prevent plagiarism by actively monitoring students' work. Evaluating students' work poses a challenge, as their focus often centers on achieving a high grade rather than fostering learning and creativity. The pursuit of an 'A' grade tends to diminish the motivation for genuine self-improvement and exploration (Kohn, 2004). The teacher overseeing the Algebra 2 class was meticulous in the assessment of students' projects. Each group that adhered to the project timeline and completed the assignment within the stipulated period received an 'A' grade. Students who submitted completed projects after the due time earned a 'B' or 'B+', with the grade adjusted according to the duration of delay. In cases where a group did not fully complete the project, they were awarded partial credit, ensuring at least a passing grade.

CONCLUSION

Utilizing digital technology to draw with polynomials plays a significant role for high school students in completing mathematical projects. It not only aids in better understanding mathematical problem-solving, function graphing, equation behavior, and real-world applications of high school math but also transforms their overall learning experience while fostering the application of creativity. The three showcased projects in Figure 3, Figure 6, and Figure 8 (depicting the bird, butterfly, and bat) beautifully demonstrate how mathematical concepts learned in high school find practical applications in real-life contexts.

Through these projects, students grasp that mathematics is versatile and applicable across various real-life scenarios, erasing doubts about the relevance of mathematical equations. The synergy of mathematical tools with artistic expression propels creativity to unparalleled heights. Amid a decline in creativity within many school districts, the importance of blending mathematical concepts with creativity becomes apparent. While many appreciate creativity and some can identify it, few can effectively apply it. Interestingly, students often exhibit elements of creativity unknowingly, particularly during collaborative projects aimed at solving real-world problems. Creativity yields optimal solutions or sparks the exploration of diverse questions.

The application of polynomials in real-life situations prompts the thought: can mathematicians utilize mathematical equations to craft superior art compared to traditional artists in the future? Above all, mathematical projects underline the synergy between mathematical and digital tools, combined with creativity, that has the potential to reshape educational landscapes.

Data Availability

The authors confirm that the results are based on data collected from projects completed by students at a technology-focused urban high school in New Jersey

1. Each figure has been taken from students' work on Google Slides at a technology-focused urban high school in New Jersey, specifically from students' projects in Algebra 2.
2. The students' work is published on a school Google Site called AlgebraMathProjects.
3. The link to the school's Google Site is accessible only within the school district.
4. The students' work on Google Site is listed in the references in alphabetical order.
5. Because of the students' privacy, data is not available for the public.

- Students work (project The Bat– google slides) at the *technology-focused, urban high school in New Jersey*, retrieved from school google site, https://sites.google.com/ucboe.us/mathprojectsalgebra/home
- Students work (project The Bird – google slides) at the *technology-focused, urban high school in New Jersey*, retrieved from school google site, https://sites.google.com/ucboe.us/mathprojectsalgebra/home
- Students work (project The Butterfly – google slides) at the *technology-focused, urban high school in New Jersey*, retrieved from school google site,

https://sites.google.com/ucboe.us/mathprojectsalgebra/home

References

Abacus, August 4, 2022. 134 Awesome Desmos Classroom Activities, retrieved from, https://abakcus.com/134-awesome-desmos-classroom-activities/

Alessandra King, 2017. Using Desmos to Draw in Mathematics, retrieved from, https://files.eric.ed.gov/fulltext/EJ1146898.pdf

Alfie Kiohn, 2004. What Does it Mean to be Well Educated? Beacon Press Books, Boston, Massachusetts.

Amy T. April 14, 2023. The Surprising Link Between Math and Creativity: An Overview, retrieved from, https://amyandrose.com/blogs/life/the-surprising-link-between-math-and-creativity/

Andres F. Arias - Alfonso and Camilo Franco, Jun 18,2021. The Creative Act in the Dialog Between art and Mathematics, retrieved from, https://www.mdpi.com/2227-7390/9/13/1517

Chick, N. (2013). Metacognition. Vanderbilt University Center for Teaching. Retrieved [today's date] from https://cft.vanderbilt.edu/guides-sub-pages/metacognition/

Creative Fabrica, Mistakes Allow Thinking to Happen, retrieved from, https://www.creativefabrica.com/product/mistakes-allow-thinking-to-happen-4/

eduTinker, November 20, 2022. Trial and Error Method, retrieved, https://edutinker.com/glossary/trial-and-error-method/

Edutopia, October 19, 2007. How Does Project - Based Learning Works? Retrieved from, https://www.edutopia.org/project-based-learning-guide-implementation

Graphing Spring, retrieved from, https://www.pinterest.com/pin/spring-graphing-mystery-picture-math-art-activity--9007267998132456/

Gregory E. Huszczo, 2009. Making a Difference by Being Yourself, Davies Black Publishing, Mountain View, California

Marko Bertamini, Giulia Rampone, Alexis D. J. Makin, and Andrew Jassop, June 17, 2019. Symmetry Preferences in Shapes, Faces, Flowers and Landscapes, retrieved from, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6585942/

Math Valut, Desmos: A definitive Guide on Graphing and Computing, retrieved from, https://mathvault.ca/desmos-guide/

Mathew Apple, Keita Kikuchi, December 2007. Practical PowerPoint Group Projects for the EFL Classroom, retrieved from, DOI:10.29140/jaltcall. v3n3.48

Minds at Work, April 21, 2016. Intuition - Its More than a Feeling, retrieved from, https://www.psychologicalscience.org/news/minds-business/intuition-its-more-than-a-feeling.html

Mithun Ekbote, May 4, 2023. The Arithmetic of Creativity: How Math Shapes Artistic Expression, retrieved from, https://www.linkedin.com/pulse/arithmetic-creativity-how-math-shapes-artistic-mithun-ekbote

Polya's Problem Solving Techniques, retrieved from, https://math.berkeley.edu/~gmelvin/polya.pdf

Outer Hebrides, Northern Gannet - Huisinis, retrieved from. https://www.visitouterhebrides.co.uk/see-and-do/northern-gannet-huisinis-p530211

Stein, D., and Wanstreet, C. E. “Role of Social Presence, Choice of Online or Face-to-face Group Format, and Satisfaction with Perceived Knowledge Gained in a Distance Learning Environment.” *2003 Midwest Research to Practice Conference in Adult, Continuing and Community Education.* (2003), Retrieved May 10, 2006 from [http://www.alumniosu.org/midwest/midwest%20papers/Stein%20&%20Wanstreet—Done.pdf]

Stephanie Ives, Algebraic and Graphical Translation of Polynomials A TELE for Desmos and Conceptual Representation, retrieved from, https://blogs.ubc.ca/stem2017/files/2017/04/Ives-533-Final-TELE-Project.pdf

Students work (project The Bat– google slides) at the *technology-focused, urban high school in New Jersey*, retrieved from school google site, https://sites.google.com/ucboe.us/mathprojectsalgebra/home

Students work (project The Bird – google slides) at the *technology-focused, urban high school in New Jersey*, retrieved from school google site, https://sites.google.com/ucboe.us/mathprojectsalgebra/home

Students work (project The Butterfly – google slides) at the *technology-focused, urban high school in New Jersey*, retrieved from school google site, https://sites.google.com/ucboe.us/mathprojectsalgebra/home

T. D. Jakes, 2014. INSTINCT: The Power to Unleash Your Inborn Drive, by TDJ Enterprises LLP, FaithWords Hachette Book Group, N.Y., New YorK.

Teach Thought Staff, April 29, 2013. 10 Practical Ideas for Better Project-Based Learning in Your Classroom, retrieved from, https://www.teachthought.com/education/better-project-based-learning/

Wentworth J., Davis J. R. (2002). Enhancing interdisciplinarity through team teaching. In Haynes C. (Ed.), *Innovations in interdisciplinary teaching* (pp. 16–37). Oryx Press.

Xiaolei Sun, Eunyoung Kim, 2022. Improving Student Creativity through Project-Based Learning: A Case Study of Integrating Innovation and Entrepreneurship Education within Product Design Courses, retrieved from Improving Student Creativity through Project-Based LearningJournal of Positive Psychology and Wellbeinghttps://www.journalppw.com › article › download