Editorial of the 2025 Special Issue

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We are delighted to present this Special Issue of the Mathematics Teaching-Research Journal (MTRJ) dedicated to highlighting faculty-led projects across the different colleges within the City University of New York (CUNY). These projects demonstrated the potential to advance STEM pedagogies and to contribute to inclusive STEM teaching and learning. An idea that emerged from the CUNY Innovative Teaching Academy (CITA) Summer 2023 Institute, this collection showcases the creativity, innovation, and diverse perspectives of educators committed to reimagining pedagogy and fostering equity in STEM education. As guest editors, we are honored to uplift and share the impactful work emerging from CUNY's vibrant academic community.

From Summer Institute to Action: Advancing Equity and Inclusion in STEM Classrooms

Sandie Han[1], Nadia Kennedy[2], Malgorzata Marciniak[3], Diana Samaroo[2]
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This Editor's Note provides background on the CUNY Innovative Teaching Academy Summer Institute for Equitable and Inclusive STEM Teaching and Learning and introduces the articles featured in this special issue. (pg. 6)

Art Forms: Born Out of Necessity

Urmi Duttagupta
New York City College of Technology of the City University of New York, USA

This collection of artworks expresses the artist's deep passion for mathematics and life's complex balance. As a mathematician who is a woman, she uses artistic expression and intricate patterns to evoke mathematical beauty and feminine strength, celebrating the presence and resilience of women in mathematics. (pg. 15)

Introducing Art into Undergraduate Mathematics Courses at Minority Serving Institutions

Renee Bell, Lehman College of the City University of New York, USA

The recruitment and retention of underrepresented minority students into STEM fields, is a critical goal for educators, particularly in an increasingly tech-oriented world and a diverse society. Research suggests that integrating art into mathematics courses can increase student engagement and broaden participation. Additionally, community-centered intellectual activities, such as such as engagement with art, have been shown to support the success of diverse student populations.

This article presents two models of integration of art into mathematics curricula. The first model involves a guided tour of an art museum, highlighting mathematical concepts found in artwork from a variety of different cultures. The second model features a student art contest focused on visual representations of mathematical ideas, culminating in an exhibition of the winning pieces. The article discusses the implementation of these models and offers recommendations for future use. (pg. 21)

Integrating Game Play into an Inclusive Computing Project in Calculus Class: Designing and Analyzing Priority Switches for Competing Devices and Apps

Małgorzata Marciniak and Yun Ye
LaGuardia Community College of the City University of New York, USA

This study explores the integration of game play into an inclusive, hands-on computing project in Calculus class. The project is focused on designing and analyzing priority switches for applications competing for computational resources on embedded devices such as smart watches and tablets. By engaging students in real-world problem-solving through the form of game play, the project enhances their understanding of mathematical concepts, particularly derivative, while fostering inclusivity in STEM education. The initiative was implemented in a Calculus class with diverse student backgrounds, incorporating structured interventions such as icebreakers, pre- and post-surveys, and interactive lab activities. A key component involved using a hardware emulation setup with an FPGA-based system to simulate communication resource competition. Survey results and informal assessments indicate that the hands-on approach increased student engagement, conceptual understanding, and interest in mathematics and technology. However, some logistical challenges, such as scheduling gaps between theory and lab activities, highlighted areas for improvement. This research underscores the importance of interactive, interdisciplinary learning experiences in promoting student participation and inclusivity in STEM fields. (pg. 39)

Metacognitive Discourse Forums as a Way to Engage Biology and STEM Students in Meaningful Discussions

Dmitry Y. Brogun and Emral Devany
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The rapidly evolving educational landscape allows, and often demands, the integration of innovative digital approaches into the curriculum. Whether the course is conducted in-person, online, or hyflex, synchronous or asynchronous, the wide range of available digital tools and platforms now offer multi-faceted learning experiences designed to actively engage students. In our biology classes, we used Metacognitive Discourse Forum (MDF), an approach to collective annotation on an assignment, which may help students develop critical thinking, metacognitive skills, and improve academic performance. The article describes the utilization of MDF in our classes and discusses its potential impact for enhancing STEM teaching and learning. (pg. 62)

Professional Development Workshops for Faculty on Addressing Implicit Bias in Computer Science Education

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The "Understanding Implicit Bias" workshops were offered to Science, Technology, Engineering, and Mathematics (STEM) faculty at an urban minority-serving undergraduate institution with a focus on addressing the gender gap in computer science. The workshops aimed to raise awareness of implicit (unconscious) biases and provide practical strategies for addressing them, fostering a more inclusive classroom environment. Analysis of pre- and post-survey responses indicated an increase in participants' awareness of implicit biases in their discipline and a greater openness to taking steps to address them, suggesting the workshops' potential impact on promoting inclusive teaching practices. (pg. 80)

Designing Equity-Focused Pedagogy in Mathematics Teacher Preparation with Digital Data Tools

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This study reflects the implementation of a course module which integrated computing and data analyses. The module focuses on engaging prospective mathematics teachers in the practice of using data sets and analyzing data to answer questions about local Brooklyn schools, and to learn more about the students and the schools where they do field experience. The module was designed to support prospective mathematics teachers in developing data analytical and critical thinking skills, and to engage them in exploring questions related to student learning opportunity, achievement gap, school segregation, education in(equity), and other social justice issues. During the course module implementation, the teacher candidates explored topics related to school (in)equity and segregation in depth, through texts, data analysis and direct experience. They shared and reflected with others on their findings, and developed a deeper understanding of the topics and questions through a process of collective discussion. The teacher candidates' perceptions of the potential of implementing computing and data analysis in mathematics teaching and learning were mixed. They considered that the use of data analysis can enhance mathematics lessons by connecting them with real-life issues such as poverty rates, student loans, and rising climatic temperature; that is, in helping students make sense of the world around them. They also agreed that it promises to provide relevance to students' personal lives and to introduce social justice issues, encourage a sense of empowerment, and act to increase motivation, which could lead to activism in their communities. However, the overall perception was that this could not be done in the first few years of teaching, as it would require much additional planning. (pg. 98)

Using Digital Tools and Real-Life Interactive Activities to Teach Trigonometric Functions

Lucie Mingla, LaGuardia Community College of the City University of New York, USA

Achieving meaningful educational outcomes requires scalable strategies for mastering mathematical concepts and skills, with student engagement at the core. This paper examines the use of comprehensive, technology-enhanced activities designed to promote active learning and deeper conceptual understanding. Specifically, it focuses on the integration of Desmos, an online graphing calculator, into mathematics instruction. The study explores whether combining Desmos with a hands-on approach to teaching trigonometric functions helps students connect abstract concepts to real-world applications. Findings underscore the effectiveness of digital tools like Desmos in increasing student engagement and improving student performance—particularly in the context of graphing and interpreting trigonometric functions. (pg. 133)

From Summer Institute to Action: Advancing Equity and Inclusion in STEM Classrooms

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Abstract: This Editor's Note provides background on the CUNY Innovative Teaching Academy Summer Institute for Equitable and Inclusive STEM Teaching and Learning and introduces the articles featured in this special issue.

Keywords: Faculty Development, STEM, teaching and learning, pedagogies

For decades, research has demonstrated the persistent barriers faced by women and students of color in Science, Technology, Engineering, and Mathematics (STEM) fields. Socio-economic, cultural, and psychological factors—such as stereotype threat, feelings of inadequacy, and a lack of belonging—continue to contribute to their under-representation and attrition (Beasley & Fischer, 2012). Additionally, systemic challenges, including academic isolation and limited access to mentorship, disproportionately affect first-generation college students, further deepening inequities in STEM education (Choy et al., 2000; McCarron & Inkelas, 2007). These disparities are compounded by classroom environments that often overlook the diverse needs and lived experiences of marginalized students. Addressing these disparities requires institutional transformation, and a commitment to equipping faculty with the tools and strategies needed to create and foster inclusive, and equitable learning environments.

The City University of New York (CUNY) Innovative Teaching Academy (CITA) Summer Institute 2023 featured a week-long STEM-focused workshop designed to directly address longstanding equity challenges in STEM education. The institute, titled *Promoting Equitable and Inclusive STEM Teaching and Learning*, focused on integrating high-impact practices—such as dialogic teaching, culturally responsive pedagogy, active learning, and instructional innovation—into STEM courses. Such implementation sought to foster student engagement and promote inclusive and equitable instruction, among other objectives. Research indicates that such approaches have been shown to improve outcomes, especially when implemented in introductory STEM courses

(George et al., 2001; Graham et al., 2013). By addressing systemic challenges, the Summer Institute also aimed at advancing the broader goal of diversifying the STEM workforce.

Faculty development is essential to advancing inclusive and culturally responsive teaching in STEM. Research shows that faculty play a key role in fostering inclusion and belonging, and professional development helps build the awareness and skills needed for inclusive teaching (Killpack & Melón, 2016; O'Leary, *et al.,* 2020). Research also shows that professional development is key to scaling high-impact practices and creating institutional changes (Biswas, *et al.*, 2022; Calkins, *et al.,* 2024). A Summer Institute offers dedicated time for faculty to discuss evidence-based pedagogical practices, collaborate across disciplines, and explore equity-focused strategies. Such efforts promise to not only strengthen individual pedagogy but to also support a broader cultural shift toward more equitable and effective STEM education.

Nineteen faculty fellows from 13 different CUNY campuses, representing disciplines such as biology, computer science, engineering, mathematics, medical laboratory science, and physics, were selected to participate in the Summer Institute. Through interdisciplinary collaboration, including a biology-English partnership and a CUNY Start (https://www1.cuny.edu/sites/cunystart/) mathematics faculty team, faculty engaged in critical discussions and workshops centered on: Understanding implicit bias; Building inclusive learning spaces: Effective DEI practices; Responsive pedagogy; Social justice curriculum; Experiential learning/Civic engagement; Scholarship of Teaching and Learning (SoTL); and Resources for securing grants.

A defining feature of the Summer Institute was its emphasis on action and accountability. At the conclusion of the institute, each faculty fellow was tasked with designing and implementing a classroom-based project, which integrated the high-impact pedagogical practices discussed during the institute. These faculty-led initiatives, spanning curriculum redesign, inclusive pedagogical strategies, expanded mentorship models, and targeted student support, were intentionally developed to address persistent gaps in STEM education and reimagine the teaching and learning environment. By embedding these innovations into their instructional practices, faculty not only initiated meaningful, immediate change but also collected data to assess effectiveness and inform ongoing refinement.

Faculty participants were not only encouraged to design and implement their projects in the classrooms, but to consider the broader impacts and scalability of their work, with the aim of influencing institutional practices across the CUNY system and beyond. Collectively, these initiatives contribute to a growing cultural shift in STEM education. These efforts highlight the transformative potential of faculty-driven innovation and underscore the importance of professional development in creating learning environments that are inclusive, accessible, and empowering for all students.

A survey administered at the end of the Summer Institute indicated that participants found value in the discussions on designing classroom activities that are inclusive, engaging, and grounded in JEDI (Justice, Equity, Diversity, and Inclusion) principles. They reported the sessions as meaningful and relevant to their teaching and professional development. Several participants shared that learning about opportunities within the Scholarship of Teaching and Learning (SoTL) offered a new perspective on how to design, document, and collect data to support SoTL work in their classrooms. Participants also expressed strong interest in connecting and collaborating to create more opportunities for future joint work. Overall, they reported that the Summer Institute had a positive impact on their professional growth.

We are delighted to present this Special Issue of the Mathematics Teaching-Research Journal (MTRJ) dedicated to highlighting faculty-led projects across CUNY that have the potential to advance STEM pedagogies and contribute to inclusive STEM teaching and learning. An idea that emerged from the CITA Summer 2023 Institute, this collection showcases the creativity, innovation, and diverse perspectives of educators committed to reimagining pedagogy and fostering equity in STEM education. As guest editors, we are honored to uplift and share the impactful work emerging from CUNY's vibrant academic community.

This special journal issue goes beyond theoretical insights, showcasing practical classroom activities, curriculum redesigns, and pedagogical strategies that reflect the principles of the Scholarship of Teaching and Learning (SoTL) (Felton, 2013). From integrating computing and digital tools to fostering critical dialogue around equity and inclusion, each article offers practical models for making STEM instruction more accessible, relevant, and responsive to the needs of today's diverse student population.

As we continue to navigate and dismantle barriers to access and participation in STEM, this issue contributes to the ongoing dialogue about what meaningful, inclusive, and high-impact education can look like. It is both a celebration of faculty innovation and a call to action—reminding us that sustained professional development, institutional investment, and collaborative learning are key to creating a more just and empowering future for all students in STEM.

We invite you to explore the work presented here, apply the ideas in your own practice, and join us in this collective effort to reimagine and reshape the STEM education landscape.

This special issue opens with three artworks by Urmi Duttagupta, titled *"In Love with Mathematics," "Woman Balancing Math and Work; She Also Has the Most Colorful Mind,"* and *"Geometric Turkey"* which express her deep passion for the discipline. As a mathematician who is a woman, Duttagupta uses artistic expression to explore the meaning of life and the precariousness of balancing different passions and obligations. Her pieces feature intricate patterns that evoke both mathematical elegance and feminine strength, celebrating the presence, resilience, and contributions of women in mathematics.

The article, *Introducing Art into Undergraduate Mathematics Courses at Minority Serving Institutions*, written by Renee Bell, explores the integration of art into mathematics instruction aiming at deepening student engagement and understanding. Through two thoughtfully designed models, a guided museum tour emphasizing mathematical themes across diverse artistic traditions and a student-led art contest centered on mathematical concepts, Bell invites students to see mathematics not only as a technical discipline but as a deeply creative and humanistic pursuit. Bells' instructional approach invites appreciation for the symmetry, structure, and aesthetics that underline both art and mathematics, revealing their shared capacity to illuminate patterns, provoke curiosity, and express beauty. By integrating these experiences into the curriculum, she creates inclusive spaces where students can engage meaningfully with mathematics in ways that affirm their identities and broaden their perspectives.

In *Integrating Game Play into an Inclusive Computing Project in Calculus Class: Designing and Analyzing Priority Switches for Competing Devices and Apps*, Malgorzata Marciniak and Yun Ye connect calculus concepts to real-world computing applications through a structured, hands-on project. Centered on the design and analysis of priority switches for embedded devices such as smartwatches and tablets, the project introduces students to game-based learning that models competition for digital resources. Within this framework, students apply their understanding of derivatives in a practical context while also engaging with elements of computational thinking. Designed to be accessible and inclusive, the project incorporates icebreakers, pre- and post-assessments, and collaborative lab work to support student learning and foster interest in STEM fields.

Dmitry Brogun and Emral Devany's article *Metacognitive Discourse Forums as a Way to Engage Biology and STEM Students in Meaningful Discussions*, explore the potential of interactive digital forums to enhance students through reflection and dialogue. By incorporating Metacognitive Discourse Forums (MDFs) and social annotations into STEM assignments, the authors created structured opportunities for students to reflect on their own learning processes and engage in interactive learning with peers. Such forums may support students across various instructional modalities while fostering essential skills such as metacognition, analytical reasoning, and collaborative problem-solving. Brogun and Devany's work demonstrates how intentionally designed digital spaces might promote inclusive learning environments and support deeper engagement and learning.

In *Professional Development Workshops for Faculty on Addressing Implicit Bias in Computer Science Education*, Sandie Han, et al., confront one of the most pressing challenges in Computer Science education today: the persistent gender gap and the subtle, often unrecognized forces that perpetuate it. Through a series of "Understanding Implicit Bias" workshops, the authors engaged faculty in critical self-reflection and meaningful discussions focused on improving classroom practices and fostering equitable and inclusive learning environments. The positive shift in faculty attitudes and increased openness to change, as shown in pre- and post-survey data, underscores the transformative potential of professional development as a driver of systemic change.

In the next article, *Designing Equity-Focused Pedagogy in Mathematics Teacher Preparation with Digital Data Tools*, authors Nadia Kennedy, Boyan Kostadinov, and Sandie Han present a design-based study featuring a course module design, its piloting, and reflection on both the outcomes and the process. The course module which involves data analysis and critical inquiry, invites mathematics teacher candidates to explore pressing social justice issues—such as school segregation, the achievement gap, and educational inequity—by engaging with real datasets from Brooklyn schools. By linking computational thinking with local, lived realities the course module helped teacher candidates see mathematics as a tool for social analysis and civic engagement. This article illustrates how critical dialogue supported by digital tools can help future teachers cultivate the analytical and reflective skills needed for equitable and culturally responsive teaching.

Finally, the article *Using Digital Tools and Real-Life* Interactive Activities to Teach *Trigonometric Functions* by Lucie Mingla presents a dynamic, student-centered approach to teaching mathematics through technology-enhanced activities designed in Desmos—an open-source online graphing tool. Research conducted over two semesters indicated that incorporating Desmos activities enhanced student performance, particularly in understanding trigonometric functions. The data suggested that early integration of Desmos activities contributed to deeper student engagement with mathematical concepts, and improved overall course outcomes. Mingla's article highlights the importance of integrating technology into mathematics instruction to design meaningful, student-centered activities that promote sense-making and foster equitable, engaging learning experiences.

Collectively, the contributions in this issue showcase high-impact educational practices that prioritize student engagement, real-world relevance, and interdisciplinary collaboration. Whether through data analysis, interactive technologies, artistic integration, or faculty development, each article highlights innovative approaches that reimagine STEM education in both rigorous and accessible ways. These approaches not only promise to enhance student learning but also to promote a sense of belonging, agency, and purpose, particularly for those historically underrepresented in STEM. By embracing innovation and accessibility as core values, the articles in this special issue reflect a shared vision for a more inclusive and equitable teaching and learning across all STEM disciplines.

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About the Special Issue Editors

I am deeply grateful and honored to have been invited to work on this special issue alongside such an inspiring group of women co-editors. It has been a true privilege to contribute to and help bring to life the vision of this remarkable team. – *Sandie Han*

Top left to right: Sandie Han, Nadia Kennedy
Bottom left to right: Małgorzata Marciniak, Diana Samaroo

Dr. Sandie Han is the Dean of the School of Science & Allied Health at Medgar Evers College. Dr. Han's illustrious career includes being a Professor of Mathematics for over 30 years. Throughout her distinguished career, Dr. Han has led numerous initiatives, including the CUNY New Lecturer Initiative, a comprehensive onboarding and professional development program for 250 new CUNY lecturers. She has served as Chair of the Department of Mathematics at City Tech, playing a pivotal role in curriculum restructuring, faculty mentorship, and departmental modernization. In addition, she was the PI on a US DOE MSEIP grant and co-PI on NSF S-STEM. She authored more than 30 articles and workbooks including 22 peer-reviewed publications in number theory and mathematics education. Her work on Self-Regulated Learning and mathematics self-efficacy won the 2013 CUNY Chancellor's Award for Excellence in Undergraduate Mathematics Instructions. An ardent advocate for faculty and students, she is committed to fostering a culture of diversity, equity, and inclusion and is one of the co-founders of the CUNY AAMPOWER which stands for Asian American Mentorship Providing Opportunities to Women for Empowerment and Resilience.

Nadia Stoyanova Kennedy is Professor in the Department of Mathematics and Program Director of Mathematics Education at the New York City College of Technology of the City University of New York (CUNY). Between completing her master's and doctoral degrees, she spent 15 years as a full-time high school mathematics teacher and a curriculum developer. She serves regularly as a consultant for the International Baccalaureate (IB) program on curriculum, assessment and examiner training. Her research interests center on philosophy of mathematics education, dialogic teaching, teacher professional identity, and teacher professional learning, with a particular emphasis on critical approaches to mathematics education and on the promotion of philosophical dialogue in the mathematics classroom. In addition to authoring numerous articles, and textbooks, she is editor of the anthology, *Dialogical Inquiry in Mathematics Teaching and Learning: A Philosophical Approach* (2022).

Małgorzata Marciniak is an Associate Professor in the department of Mathematics, Engineering and Computer Science at LaGuardia Community College of CUNY. She is an author of multiple publications in pure and applied mathematics, and in mathematics education. She serves as the Managing Editor of the *Mathematics Teaching-Research Journal*, an international journal of mathematics education; as an Acting Editor in Chief of the *Asian American Voices*, and an Editor for the scientific newsletter, *Ad Astra*. In 2024 she co-edited a book *Ongoing Advancements in Philosophy of Mathematics Education* and in 2025 she published a book *Creativity in STEM Fields: a View from and Eclectic Mind* about creative projects in collegial mathematics classes. Dr. Marciniak is interested in theories of creativity and in seeing mathematics "everywhere."

Dr. Diana Samaroo is a Professor of Chemistry at New York City College of Technology (City Tech), CUNY. Her profile highlights a strong blend of administrative and research expertise, and a deep commitment to faculty development, student success and diversity. Dr. Samaroo has held several administrative positions at the college: Chairperson of the Chemistry Department; Director of the Dr. Janet Liou-Mark RISE Program, administering a program funded by the Robin Hood Foundation that serves first year students, and Associate Director of Undergraduate Research. She is a 2024-2025 University Faculty Leadership Fellow in the CUNY Office of Faculty Affairs. Dr. Samaroo serves/d as co-principal investigator on several National Science Foundation (NSF) grants. In 2025, she co-organized the CUNY wide Teaching and Learning Conference and in 2023, the inaugural NSF HSI CUNY-Wide Conference, and previously the SENCER Mid-Atlantic Regional Conference and the 13th Annual Black Male Initiative Conference. In 2024, as a co-principal investigator, she received a three-year award from the National Endowment for the Humanities for a project on "Enriching the Humanities Curriculum to Embrace Cultural Relevance," which focuses on curriculum development, faculty professional development workshops, and partnerships with Hispanic Studies departments across CUNY. As a biochemist, Dr. Samaroo's productivity as a researcher earned her City Tech's "Scholar on Campus" award for 2022-2023. Her dedication to advancing students, faculty, and the institution's mission is a common thread woven through all her work.

Art Forms: Born Out of Necessity

Urmi Duttagupta

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Abstract: This collection of artworks expresses the artist's profound passion for mathematics and life's complex balance. As a female mathematician, she uses artistic expression and intricate patterns to evoke mathematical beauty and feminine strength, celebrating the presence and resilience of women in mathematics.

My art reflects the social issues that matter to me. My work also frequently celebrates nature and its beauty through vibrant colors. Often, it incorporates geometric patterns and mathematical symbols, signifying my passion for mathematics. As my full-time professorship and motherhood became increasingly demanding, I found it challenging to find time for my hobbies. Feeling unhappy and incomplete, I desperately sought a way to follow my passion. A few years ago, I began doodling with pens and markers to express my thoughts as a distraction—creating repetitive geometric shapes. To my knowledge, I am not aware of anyone who used this technique during that time. Working with markers is mess-free and requires almost no preparation. Thus began my journey with colors, utilizing a drawing pad, pens, markers, and pencils. I started drawing during my daily commute on the bus and subway, at the airport, or on the plane during my conference trips. In other words, emerging from necessity, this technique provided a sustainable way to pursue my dream while bringing a sense of purpose to my life.

I embrace spontaneity and freedom in painting and drawing, rejecting standards and boundaries. Instead of an unembellished representation of nature or contemporary life, depicting subjects as they are, I enjoy capturing moments of life, nature, or social contexts with vibrant colors, breaking down subjects into geometric patterns and shapes, and combining abstract expression with realism. I relish deconstructing an art form into several puzzle pieces, allowing the audience to decide the perfect fit and discover the mystery of the art. All the artwork presented here represents breaking barriers and presenting mathematics, art, music, and other traditional forms unconventionally.

Specifically, the *Woman Balancing Math and Work* was created from a study of a still life. Being forced into isolation and restricted in movement during the COVID-19 pandemic, I sought an escape from the chaos and morbidity. This gave birth to a woman, a mother who finds joy in colors, possesses the most colorful mind, and knows how to balance mathematics and work. This artwork features repetitive patterns of geometric shapes, mainly circles, overlapping each other to highlight the complexities and chaos of a pandemic. Amid all this chaos, she still dreams of a colorful and hopeful world.

Figure 1: Woman Balancing Math and Work; She Also Has the Most Colorful Mind – pen and marker

Figure 2: In Love with Mathematics (Black and white) - pen

Figure 3: Study of Guitar; Quote embedded in the drawing: Where the world fails, music prevails. Original quote by Hans Christian Anderson's: "Where words fail, music speaks." - pencil

Figure 4: Geometric Turkey – pen and marker

Figure 5: Me-factor – paper collage

Urmi Duttagupta is the Computer Science Program Coordinator and a Mathematics Department Professor at New York City College of Technology. Her current research interests include infectious disease modeling, applications of graph theory in criminal network analysis, and the development and application of bio-math-related undergraduate modules. She has received many grants including MAA NREUP, a SENCER leadership fellowship, Department of Homeland Security (DHS), and several NSF S-STEM and PSC-CUNY grants. She has mentored more than 45 students in different research projects through the Emerging Scholars program, Honors Scholars program, NYC LSAMP grant, CURM mini-grant, MAA NREUP grant, and DHS grant for undergraduate research. She is originally from Kolkata (Calcutta), a cosmopolitan city in Eastern India. As an Asian American, she embraces multiculturalism and diversity. She considers herself a lifelong learner and is always eager to learn from her students about their cultures and traditions. Besides solving math problems, she enjoys reading, painting, writing, singing, whimsical dancing, and cooking spicy Indian food.

Introducing Art into Undergraduate Mathematics Courses at Minority Serving Institutions

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Abstract: The recruitment and retention of underrepresented minority students into STEM fields, is a critical goal for educators, particularly in an increasingly tech-oriented world and a diverse society. Research suggests that integrating art into mathematics courses can increase student engagement and broaden participation. Additionally, community-centered intellectual activities, such as engagement with art, have been shown to support the success of diverse student populations. This article presents two models of integration of art into mathematics curricula. The first model involves a guided tour of an art museum, highlighting mathematical concepts found in artwork from a variety of different cultures. The second model features a student art contest focused on visual representations of mathematical ideas, culminating in an exhibition of the winning pieces. The article discusses the implementation of these models and offers recommendations for future use.

Keywords: inclusive teaching, STEAM, nontraditional students

INTRODUCTION

Black and Hispanic students remain an underrepresented minority in mathematics across the United States. Underrepresented minorities often find themselves excluded from mathematics courses in a pattern frequently described as a "pipeline" issue, where increasing numbers of marginalized individuals leave the field in later stages of their career preparation (Wightman Brown 2002). To support broader participation of underrepresented students, we propose two models for integrating art into the mathematics curriculum: Model 1, a guided mathematical tour of an art museum, and Model 2, a student art contest featuring mathematical themes, culminating in an exhibition of the winning entries.

This article presents supporting literature for these two models, details their implementation (including design and results), and offers suggestions for other educators interested in adapting them to their own settings. The participants in these projects were Lehman College undergraduate students. Lehman College is well-established as a minority-serving and Hispanic-serving institution located in the Bronx, New York. Hispanic students make up 49.9% of the student body, and 32.3% of the students identify as Black. The campus is represented by 118 cultures, and 24% of our students were born outside of the United States. In addition, Lehman College has a large number of non-traditional students: 51.9%, of the students are over the age 22, 57% are first-generation college students, and 54% come from households with a total income below $30,000/year (Lehman College 2024).

LITERATURE REVIEW

The following summary highlights key findings from the literature that underscore the potential of the two models to enhance participation and achievement in mathematics among underrepresented student populations.

Art and Mathematics

Art has enormous potential to enhance learning mathematics, due in part to the descriptive nature of mathematics. A crucial part of the work of mathematicians is to develop the "right" definitions as well as identify and articulate notions of similarity in ways that correspond to our intuition. Dobson and Prentner (2023) argue that "the arts play a special role in mediating between the precise statements of mathematics and the sometimes fuzzy nature of our experience. Mathematics and art are complementary ways to come to a comprehensive understanding of reality." (p. 1)

Art interventions in mathematics courses may be especially beneficial for minority students who speak English as a second language. For example, an analysis of an arts related intervention in a fifth-grade curriculum showed that a STEAM (Science, Technology, Engineering, Arts, and Mathematics) intervention produced significantly higher science learning gains for both English fluent and emerging bilingual students with greater advantages for bilingual students (Hughes et al 2022). Similarly, Glaz and Liang (2009) found that integrating poetry into a college mathematics class reduced anxiety and increased attendance and performance.

Additionally, storytelling has emerged as a feature of some student projects in a course where Model 2 was implemented. In "Teaching Mathematics as Storytelling," Zazkis and Liljedahl (2009) present a rich variety of pedagogical roles and functions that stories can serve in mathematics classrooms, offering several complete examples. Their work illustrates how stories can be used to pose mathematical questions, frame mathematical concepts, and engage and entertain students (Zazkis & Liljedahl 2009). Harding (2018) included stories about mathematicians in a calculus class for engineering students, and received enthusiastic feedback, and motivated attendance. Papadimitriou (2003), drawing on narrative psychology and personal experience, makes a compelling case for incorporating storytelling into computer science education. For example, he teaches the depth-first search algorithm using the myth of Theseus and Ariadne. Schiro (2004) likewise presents engaging examples of storytelling in mathematics instruction, highlighting its pedagogical potential.

Ethnomathematics

Model 1 provides a natural way of weaving ethnomathematics into tertiary mathematics curricula. D'Ambrosio (1985) defines ethnomathematics as the mathematics which is practiced among identifiable cultural groups, including cultures outside of the Western tradition. In particular, inclusion of mathematical traditions from a more diverse range of cultures can be affirming for students from underrepresented backgrounds and increase their appreciation of mathematics (Frankenstein & Powell 1989, p. 110). This approach can be extended to abstract and advanced topics. For example, Bockarie (1988) used a Mende notion of adding sets to teach the concept of a homomorphism in an abstract algebra class at Njala University College in Sierra Leone. In addition, integrating "culturally diverse and relevant examples" of mathematical practices from various cultures are known for cultivating classroom equity (Tanner 2013). Indeed, classroom activities involving students' cultures can be used to valorize the culture and stimulate creativity, a necessary skill for mathematical problem solving (Suherman and Vidákovich 2022).

Anderson (1990) recounts a powerful testimony of his own integration of ethnomathematics into the classroom.

> Primarily the results of my two decades of evolving a non-Eurocentric approach to teaching mathematics are reflected in my students having a more positive, self assured attitude about themselves successfully doing mathematics. For example, of the hundreds of students that took my algebra classes at the State University of New York, Old Westbury (1971-1977) and Rutgers University in Newark (1986-1989), 85 percent passed the course. Out of these about 60 percent pursued at least one more mathematics course that they initially had planned to avoid. Over that ten-year period many more African American students began taking and passing the precalculus courses at both these sites—an increase of 25 to 28 percent at Old Westbury and a 19 to 21 percent increase at Rutgers, Newark. Conversely, among students enrolled in the traditional algebra lecture and testing formats at Old Westbury dropout and failure rates increased from 1978 to 1988. In basic algebra classes at Rutgers,Newark, the failure and dropout rates have hovered at around 50 percent for the past seventeen years!"(Anderson 1190 p. 358)

Community Building

This kind of involvement can positively impact not only the students themselves but also their communities. In a study of eighth grade ethnic minority students, Smith and Hausafus (1998) show that "students have higher test scores if parents help them see the importance of taking advanced science and mathematics courses, emphasize the importance of mathematics in today's careers, set limits, and visit science/mathematics exhibits and fairs with their child. (p. 111)"

Similarly, a study of Hispanic college students in STEM, family support and small communities were two of seven themes for success (Wightman Brown 2002).

In the author's implementation of both models, students engaged their family members—including parents and children— in the activities.

METHODS

Model 1

The first model is a guided tour of an art museum, emphasizing the mathematical concepts found in selected works of art. This model includes a) selection of a museum, b) conducting a preparatory literature review, c) completing a personal preview tour, d) motivating student attendance and facilitating the tour itself, which involves e) an introductory discussion, f) preparing rigorous math questions, g) raising questions connecting the human experience to mathematics. The experience is concluded with a slideshow summary presented in a subsequent class session.

a) An ideal museum for this activity features artwork from a vast array of cultures, particularly Islamic art, which often displays rich and evident mathematical patterns. A museum that offers discounted admission for local residents is also advantageous, as it may encourage low-income students to become more familiar with the intellectual and cultural resources of their city.
b) Preparation of the tour begins with some research into the museum's own resources and the broader literature. Many museums offer educational resources on their own website, including resources for mathematics instruction. For example, the Metropolitan Museum of Art (hereafter referred to as the Met) offers mathematical activities centered around its collection of Islamic art (Metropolitan Museum of Art 2003) and Scientific American has detailed the mathematical dimensions of various pieces at the Met across multiple genres (Dauben & Senechal, 2017). Preparation should also include reviewing a broad set of mathematical ideas that arise in diverse cultures, for example the ones discussed in the anthology *Ethnomathematics* (Ascher, 2017). Exposure to such examples can help instructors recognize mathematical elements in traditional art that they may otherwise overlook. Literature review can also inform of methods for incorporating specific cultural practices into mathematics curricula (Gerdes, 1988).
c) The next stage of preparations is the instructor conducting a personal preview tour of the museum. The instructor should go through each exhibit at length, looking carefully for mathematical examples, writing down notes and mapping connections with mathematics, informed by the readings. Nearly every exhibit has the potential to reveal connections to mathematical content. For example, at the Met, the modern and contemporary art exhibits feature sheared cubes, a binary tree, and the net of a tesseract. Folk and ceremonial art can bear inscriptions or decorations with mathematical content as well, for example, African musical instruments at the Met display etchings of knots. Exhibits may also

feature games, like historic chess sets or dice, which can spark discussion about probability and combinatorial games.

d) When announcing and advertising the tour, the instructor might encourage students to bring friends and family, with the goal of expanding student intellectual community and support networks. The instructor could provide extra credit to students attending the tour.

e) The tour could begin with a short discussion on how mathematical ideas arise in art in a variety of cultures, and can include compelling examples that the instructor found which are not included in the museum's collection. At this point, the instructor could also explicitly encourage students to look for art pieces that reflect their own cultural background, experiences, or knowledge. This can include cultural attire, historical references, or crafts. Students should be invited to point out these pieces to the group, and share their own knowledge and insights–mathematical or not–about their cultural significance.

f) During the tour, the instructor could pose mathematical questions to the students, asking them to describe features of the art piece they are viewing and using mathematical language and concepts, and to connect the art with what they had learned in class. The instructor can include prompts that encourage them to wander and find their own examples, such as: "walk around this gallery with your classmates and pick a piece you like. Describe a way in which that piece is symmetric, giving an explicit linear transformation if you can." Questions can also focus on specific mathematical aspects of a piece, ideally starting with broad observations of the students about it, and honing in on a rigorous description. For example, for a piece with 4-fold symmetry, the instructor can ask evocative questions such as "What number would you associate with this image?" followed by "Why four? Which details of the image relate to the number four?" followed by "what is the matrix for the symmetry here, what happens when we raise it to the fourth power?" The ensuing discussions can be supplemented by exercises on paper that the students can do together: for example, "this vase is a surface of revolution–what is the generating curve?" or "physically perform this symmetry on this sheet of paper by rotating and reflecting it."

g) Questions connecting the mathematical aspects of art pieces to practical and philosophical aspects of human experience can be especially compelling and motivating for students. For example, pieces with orientation-preserving symmetries are more likely to have inscriptions of text, prompting students to consider "What happens to words under different types of symmetries?" and "How do the matrices representing these symmetries differ?". Students can be asked about how the construction of the pieces relates to math, e.g. "How do you think this ceramic vase was made? How does that relate to our concept of a surface of revolution?" Pieces may have representations of numbers, like Roman or Arabic numerals; students can be asked about the advantages and challenges of different number systems, and the instructor can also teach them about Babylonian base 60 and Aztec base 20. Questions can center around structure as data preservation and record keeping, for example: "how do symmetries allow us to recover information about an art piece if part of it is lost or damaged?" Religious art provides a natural opportunity for philosophical and historical questions. For example, when looking at an astrolabe, "what might prompt such a widespread knowledge of location and orientation?" (finding the direction of Mecca). As another example, when looking at a plane tiling, "Islamic art often evokes the infinite. What is infinite about this piece?"

In the lecture following the trip, the instructor could present a slide show of pictures taken during the trip, and students who attended could be invited to share their experience, so that students who were unable to attend learn about it, and engage with the material. The instructor can also ask all students questions about specific pieces photographed by their peers, fostering inclusion.

Model 2

The second model outlines the design of a mathematical art prize for students. This model requires a) a pedagogical focus for the prize, b) a detailed, encouraging submission form, c) an intentional recruitment strategy, d) advertising for a public viewing event, e) agenda for the viewing event, and f) a plan for a long-term display of the winning entries.

a) The prize should recognize artwork which depicts an important and challenging math concept in a way that helps viewers gain understanding of the concept, with the idea that these works could play a pedagogical role in the department. Students enter by submitting a draft of 2D or 3D visual art (like a painting, digital image, or sculpture), as well as a short (roughly 3-6 sentence) narrative statement about how they engaged with and represented the mathematical concept.
b) The instructor should create an informative online form for prize submissions. The form should include a rubric (or general guidelines), which allows students to understand the criteria for winning. The rubric can include points for: pedagogical strength/insight into the mathematical concept, artistic creativity/originality, and strength of the narrative statement. The form can also include some examples of mathematical art for inspiration. The prize should be announced early in the term, with a deadline for submissions late in the term. This way, students can spend time thinking of how they will depict the concepts they are learning, and possibly take inspiration from art museum trips. Asking for a *draft* lowers the barrier to entry and avoids wasting potentially expensive materials for those who are not selected, and this should be communicated to the students. Once winning entries are selected, there is a second deadline for winners to realize their drafts as final products.
c) Recruitment must be intentional and strategic. General open calls via email often yield limited participation, especially since students are busy, and may not feel confident enough in their mathematical or artistic abilities. Entry into the prize should be a mandatory assignment in one's own class, and the instructor should encourage colleagues in their department to offer extra credit for participation. The instructor should personally visit classrooms to announce the prize and answer questions from students about it; this can be a place to emphasize that the prize is not just for students with high levels of technical art skill. Visiting classes which students find most difficult is especially

valuable. In these courses, offering an extra credit can be a strong motivator. The invitation for visualizing mathematics concepts can spark interest and engage students more deeply with the material. Prize-winning entries from these classes can provide inspiration and examples for future students.

d) The instructor should organize a viewing event for the art prize entries, which is advertised to the campus community and beyond. Students should be encouraged to bring friends and family. The event should be advertised as a celebratory occasion – like a gala–with formal attire encouraged but not mandatory. The instructor should provide refreshments to help create a festive atmosphere.

e) The instructor should set up the room like a gallery with art pieces displayed on easels, dispersed throughout the room. The display can include pieces which did not win but were notable! Prizewinners should take turns speaking at a podium, describing their artwork and explaining how they came to understand the mathematical concept it represents. The prize can also include a visual keepsake that celebrates the student's success, such as a mathematically themed trophy or a Möbius sash. Then, students can stand by their displayed artwork while visitors circulate, view the entries, and talk to each artist about their piece.

f) After the ceremony, the winning entries should be displayed in the math department alongside photos of the artists, increasing visual representation in the department. Another aim of displaying the artworks in the math departments is to expose passersby to beautiful mathematical ideas, which may pique their curiosity about these classes and encourage them to enroll.

RESULTS

Art Museum Trip

Nine students attended the art museum trip, two of whom had never been to the Met before, despite being longtime New Yorkers. Student remarks during the art museum field trip implied a deepening understanding of linear transformations. Sometimes, different students described the linear transformations preserving a piece in different ways and were excited to realize that the transformation was actually the same (for example, a horizontal reflection after a vertical reflection amounts to rotation by 180 degrees).

Figure 1: Students at the museum (photo taken by Renee Bell)

One student was particularly excited to see a representation using hangers of a binary tree, which he had learned about as a computer science major: he remarked on it during the trip, and in the questionnaire wrote “I loved the simple use of a binary tree in the modern contemporary art collection at the museum. Binary trees are powerful tools used for searching and sorting.”

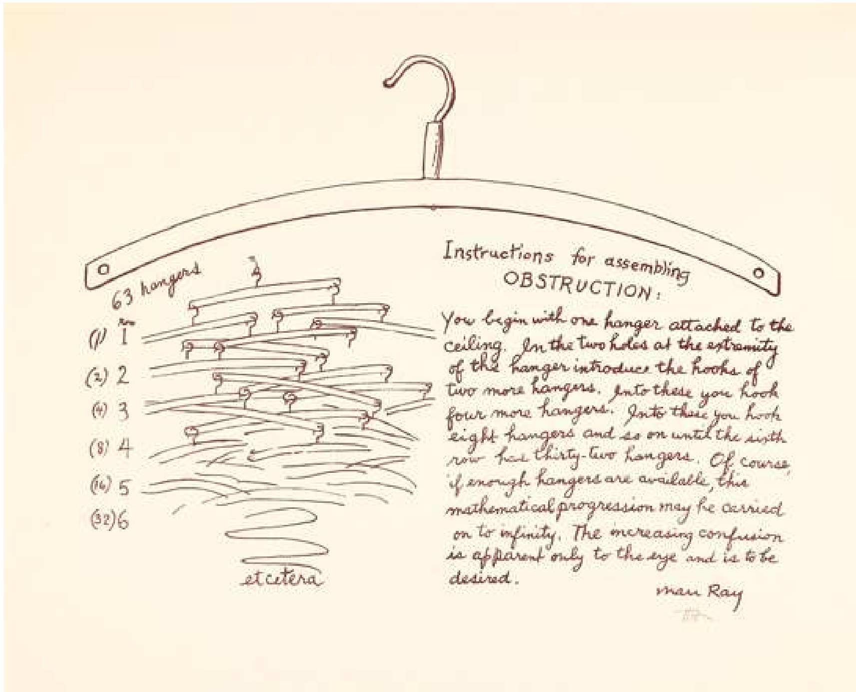

Figure 2: Instructions for assembling "Obstruction," by Man Ray (Source: http://radicalart.info/kinetics/Turn/MobilesAMain/index.html)

Another computer science major when seeing an image of a quipu, a device made of tasseled string which recorded information in the Inca empire, exclaimed in delight "It's all data! Art is data!" and noted one could wear it as a necklace, and use fashion to record data. Another student immediately recognized statues of the woman pharaoh Hatshepsut, about whom she had learned in previous studies, and she gave the rest of us a small history lesson about Hatshepsut. The same student, who is Nigerian, also pointed out robes from Nigeria and described their role as ceremonial attire.


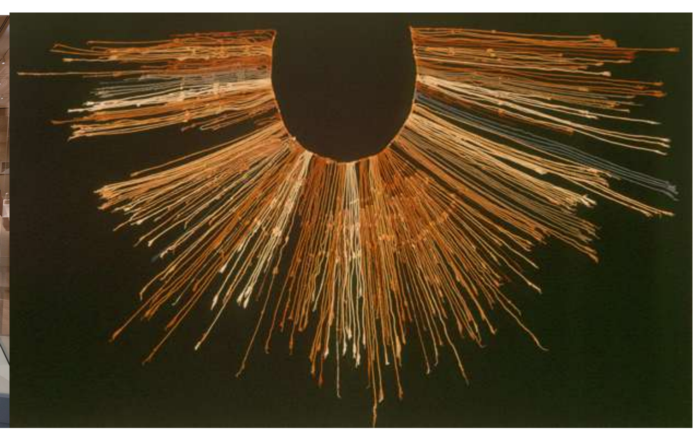

Figure 3: Left: Riga (photo taken by Renee Bell), a ceremonial robe from Nigeria. Right: Quipu, Incan recording device (Source: https://en.wikipedia.org/wiki/Quipu)

A favorite piece among the students was a panel of tiles in the Islamic art section. The tiles were highly symmetrical, and though several tiles were missing, viewers and historians could use the symmetries to reconstruct the images on the missing tiles. One student would later use this image, which she described as a "geometrically composed puzzle," as the basis for her art project.

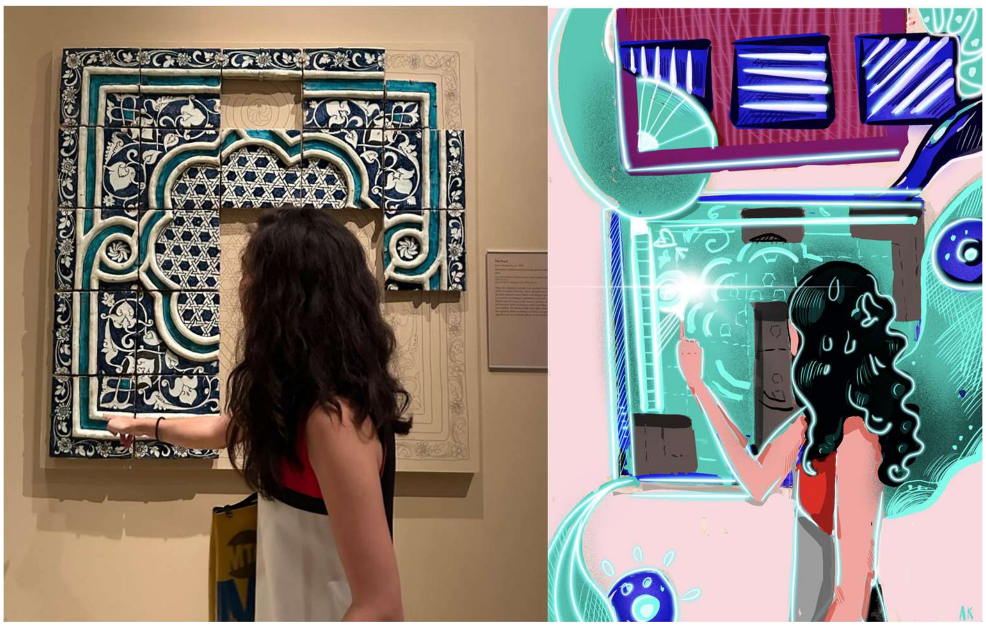

Figure 4: Left: Image of the tile panel at the Met museum (photo by Renee Bell). Right: Digital art by student Albina Krasykova.

Students' responses in the post-field trip questionnaire evidenced an expanded understanding of the manifestations of mathematical ideas. One student wrote:

> When I try to learn a new concept related just to anything, I often strive to have a real world example. How is it useful, and what the real world example would look like. The professor from our class did a great job with illustrating, mapping concepts to an art piece from the Metropolitan Museum of Art. It was exciting to visit the exhibition with the class, and listen to the professor's explanation of the concepts embedded into each of the artworks.

Another student wrote "This trip helped blur the lines of math, science, history, and art. Math can be simple and beautiful. It can also be harsh and complex. I will continue to walk through life associating the two properties together." The tour was prefaced with a discussion which included the following example from the Museum of Fine Arts in Boston. In Japan, artists were aware of perspective techniques providing the illusion of 3-dimensional depth somewhat early on, and these techniques were used in some settings, but not broadly used since they were considered gimmicky, perhaps like we view 3D IMAX movies today, which do not comprise the majority of movies. One student reflected on this: "...just because certain artistic aspects or art styles are not heavily represented in certain cultures does not mean that they did not know about it or how to do it. I found this really profound." One student, who is a postal worker, wrote "Who knows, maybe one day I will find something truly spectacular on my route," suggesting he will carry a mathematical lens into his day job and look for sources of inspiration while at work.

Students also bonded with each other on the trip in surprising ways. One student wrote "Besides aiding me in my much needed imagery of what some of the concepts actually do (perform), this trip gave me a great opportunity to connect more with my classmates and get to know them better." One of the students brought her toddler, who ran all around the museum ecstatic about the art, even asking his mother if they could bring some home. Students referred to him as a future linear algebra student, envisioning a continuity of STEM higher education, and took turns holding him.

Art Contest

For the art contest, 15 students submitted drafts for consideration. Students from six core courses were targeted for recruitment, and submissions came only from courses which the author personally visited, advertised the contest, and took questions.

The entries were diverse and original, stepping outside of the most common themes of mathematical art. The student who created the piece depicted in Figure 4 wrote "I depicted my professor explaining the concept, since she was the source of the inspiration, and motivation behind me wanting to learn and succeed in the Linear Algebra class." Her artwork depicted not only symmetries and art from other cultures, but the experience of exploring these ideas in a museum. Another entry was by a student who was a professional dancer since he was 8 years old, and is in the process of starting anew and getting a degree in computer science. His entry was a still from a music video he danced in years ago, in which his shadow was projected onto a sheet of fabric. The image was beautiful and a favorite among the judges: the silhouettes of the dancers clearly illustrated their motion and the blurred edges of the shadow had a hint of color, reminding the viewer of the 3-dimensional origin of the image. This student wrote "Trying to master the topic of linear transformation was too convoluted by myself. It was in class, through various every-day examples that I was finally able to grasp the general meaning of the theorems and linear algebra practices. Since then, I always associate R3 -> R2 transformation with shadows on a wall. In my submission that is what I am showcasing with a light source coming from behind the subjects, one of whom is me."

Figure 5: Left: Student art draft by Shirley Paulino. Right: 3D-printed hyperbolic helicoid

Another student submitted a draft with an elegant sketch of a hyperbolic helicoid, and surprised me by 3D printing her final entry, incorporating her skills and hobbies external to her math class (these are pictured in Figure 5). Another entry was a glowing, ghostly digital image of the Manhattan Bridge, incorporating the architecture of New York. Two students incorporated Pacman into their pieces, one depicting Pacman eating the pivots of a matrix in an illustration of Gaussian elimination for row reduction, and another to indicate movement along a solution set. Another student created a graphic of a rotating infinite 3-dimensional grid of spheres; the spheres were reflective and illustrated the rotation in a striking way. Another student illustrated the linear transformation performed by a specified matrix with a fantasy character in armor standing over a reflection.

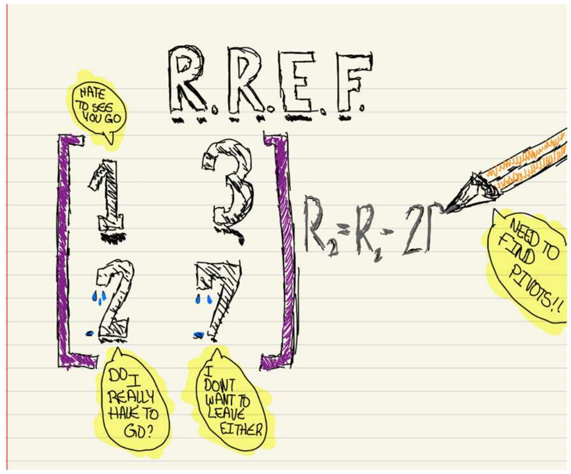

Figure 6: Depiction of of Gaussian elimination by student Jasmine Demoya.

Another student illustrated the Gaussian elimination algorithm with a cartoon (Figure 6). She anthropomorphized the entries of a matrix, pitting the pivot against a weeping nonzero entry below it who was about to be eliminated, an operation orchestrated by a scheming pencil. Gaussian elimination, which is a difficult and somewhat rote algorithm, is not depicted visually in standard textbooks or mathematical art, but two students used their art to tell a story about this algorithm and bring it to life in a creative way.

Mathematical Art Exhibition

The gallery viewing event was attended by about 25 people, including the professor of one of the winning students, another Lehman College math professor who is also a jazz musician, the undergraduate math advisor, and a math professor at New York City College of Technology. Many of the other attendees were friends and family of the winning students. However, no students attended who did not have any personal connection to the winning students. Displaying the artwork of all students who submitted entries, including those who did not win, may have been a more inclusive approach and may have brought in more attendees.

Figure 7: left: Exhibition attendees discussing art; right: Refreshments arranged in mathematical pattern (photos by Renee Bell and Sandie Han).

The event was a very positive experience for the winning artists and the attendees. The winning students talked excitedly about their art with captivated attendees, who looked at every piece. Conversations were lively and continued for over an hour. Students were very proud of their work and brought their loved ones: spouses, friends, parents. The advertisement explicitly stated that formal attire was encouraged, but not required, so that students and attendees had the freedom to either indulge in celebratory glamor or wear their usual comfortable clothing. The predominant culture in mathematics is very informal in this respect, with famous mathematicians often speaking at conferences in T-shirts, shorts, and sneakers, and undergraduates sometimes find themselves conspicuously overdressed at their first event; indeed, the unstated expectations around attire can be a source of anxiety for students who are new to the scientific community. The results were that attendees and student winners showed up in a broad range of formality levels, and the atmosphere was friendly, inviting, and celebratory.

Survey

The students in the author's linear algebra course were surveyed at the beginning of the semester and after the end of the semester. A total of 7 students (out of 28) returned the survey in the end: the following results are for those seven students. The average for the answer to "I can succeed in mathematics" fell from 4.5 to 4.36. This may reflect that MAT313 is a significant escalation in difficulty from calculus, but warrants a more careful and thoughtful approach for my own future iterations of this class. However, the average answer to "I would consider majoring in mathematics" rose from 3.14 to 3.71, suggesting that student interest rose despite student acknowledgment of the difficulty of mathematics.

Lastly, the average answer to “I know of the contributions of people of many different cultures to mathematics” rose from 3.14 to 3.86.

Math art contests recognize and reward skills which students have developed outside of the math classroom, be it 3D printing or ballroom dance. Such events have the potential to bring new layers of students into mathematics, students who have focused on developing other skills in their studies and lives; this is consistent with the rise in students’ consideration of being a math major.

DISCUSSION

Nontraditional students

These experiences show that math art events can build and fortify an intellectual community for nontraditional students, reaching the broader community while also reinforcing student support. At Lehman College, many students live with their families, and there are no dormitories. This results in an organization of scholarly life which differs from schools in which most students live on campus; the family members with whom our students cohabitate, which includes the parents and the children of our students, are often not currently enrolled in college and not actively studying mathematics. Art is an engaging way to communicate about mathematics with people from a broad range of mathematical backgrounds, and indeed, at the mathematical art exhibition, students discussed their pieces with the parents who attended, bringing their families into their intellectual lives and the community at Lehman College. Art can also be particularly engaging for children, and a way for students who are parents to introduce their own children to mathematical ideas and include their children in their education. These effects align well with the mission of CUNY in particular, which aims to educate the working class of New York, a community which includes the families of our students. Events which take place outside of lecture time, like the field trip and the art exhibition, also provide a space for students in the same class to bond and socialize in ways they otherwise may not have.

Future implementations

The implementation of Model 1 could be adapted by visiting other museums (for example The Museum of the American Indian), with an eye toward the examples in Ascher (2017). The implementation of Model 2 could be improved by expanding recruitment, and by highlighting and celebrating the contributions of more than a select few winners, thereby broadening participation and increasing the number of students who benefit from the project. Lastly, an expansion of funding for prizes, art materials, framing and mounting of art pieces, and field trips, as well as increased administrative and institutional support for these efforts, would encourage more projects like this in math departments.

CONCLUSION

The implementation of these models (a mathematical art museum tour and a student mathematical art prize) for integrating art into math curricula exposed students to extensive cultural diversity in the academic setting, directly engaged students' family and community members, drew out student creativity and inspiration in surprising ways and from surprising artistic sources, and sparked enthusiasm and lively discussion from every participant. This shows that these models have the potential to broaden participation among underrepresented minorities in math, that the models and their motivating principles merit more rigorous study, and that similar projects can be fruitfully implemented in other math courses.

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Integrating Game Play into an Inclusive Computing Project in Calculus Class: Designing and Analyzing Priority Switches for Competing Devices and Apps

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Abstract: This study explores the integration of game play into an inclusive, hands-on computing project in Calculus class. The project is focused on designing and analyzing priority switches for applications competing for computational resources on embedded devices such as smart watches and tablets. By engaging students in real-world problem-solving through the form of game play, the project enhances their understanding of mathematical concepts, particularly derivative, while fostering inclusivity in STEM education. The initiative was implemented in a Calculus class with diverse student backgrounds, incorporating structured interventions such as icebreakers, pre- and post-surveys, and interactive lab activities. A key component involved using a hardware emulation setup with an FPGA-based system to simulate communication resource competition. Survey results and informal assessments indicate that the hands-on approach increased student engagement, conceptual understanding, and interest in mathematics and technology. However, some logistical challenges, such as scheduling gaps between theory and lab activities, highlighted areas for improvement. This research underscores the importance of interactive, interdisciplinary learning experiences in promoting student participation and inclusivity in STEM fields.

Keywords: *calculus, inclusive education, STEM, derivative, game play, interactive learning, priority switches*

INTRODUCTION

In our project, we aim to make mathematics classes more engaging and relevant for engineering and computer science students. Our primary focus is on fostering active learning while creating an inclusive environment, particularly for minority and female students. To achieve this goal we thoughtfully structured group activities, allowing students to collaborate with peers who share similar backgrounds, majors, or identities while also providing opportunities for diverse group interactions. This practice helps build a sense of belonging while encouraging broader perspectives.

Recognizing that students are highly motivated by hands-on, interactive experiences, we created an atmosphere of curiosity – one that sparks excitement about "what's happening in class" and, in turn, cultivates deeper engagement with assignments. To better support underrepresented students, we introduced targeted interventions before the beginning of major class projects. These included initiatives such as class icebreakers, pre-project discussions, pre-surveys, dedicated in-class discussions, post-surveys, and small-group conversations with instructors.

Institutional Profile

Fiorello H. LaGuardia Community College of the City University of New York is known for its multicultural and diverse environment and a highly heterogeneous student body. This second largest urban community college is located in Long Island City and serves over 45,000 students from the metropolitan area. Over 60% of students live on low financial supply, often handling multiple jobs, taking care of their families and facing extreme life hardships. The heterogeneity of the population of students is at the same time a challenge and a benefit since there is a visible group of ambitious and hardworking students who already have detailed plans for their professional careers, in particular for transferring to a four-year college and earning a bachelor's degree. The Department of Mathematics, Engineering, and Computer Science offers mathematics education to all majors. It was the departmental and college initiative to introduce inclusive projects in mathematics classes of all levels, including developmental courses. Sample class projects are available via departmental web page, and instructors are encouraged to create their own projects and seek feedback from the course coordinators. Previous experience with project-based learning places students at an advantage when they join a summer or a year-long research project or transfer to a 4-year college.

LITERATURE REVIEW

Inclusive mathematics classrooms can be fostered through a manifold of pedagogical and didactical approaches, by physical and organizational environments, and by student-centered learning environments (Höveler 2019). Research indicates the importance of hands-on activities, real-world applications, and adapting curriculum to be relevant to students, all of which contribute to a more inclusive setting (Faragher 2016).

To create inclusive mathematics environments, educators should have critical consciousness, use a more expansive view of mathematics, adapt curriculum and instruction to be relevant and engaging, include experiential learning, collaborative work, and prioritize deep mathematical thinking. Incorporating activities that allow students to physically interact with mathematical ideas enhance their understanding and interest in math study (Faragher 2016). Using tailored materials and visual aids can help develop concepts thoroughly (Gardesten 2023). Connecting mathematics to real-life situations improves student performance (Faragher 2016). Collaborative teaching models engage students alongside general and special educators and community professionals in problem-based activities (Malian 2011). Co-teachers can support activities through professional development that creates content-rich and differentiated instruction for all students (Malian 2011). Mathematics curriculum and instruction should be adapted to be relevant to all students in the class. Inclusive learning environments require teachers to notice, relate, and adjust their approaches to meet students' individual preferences and prior knowledge (Höveler 2019). Teachers who recognize that students are experts on their own uses of mathematics can engage students as key contributors to their own learning.

Inspired by these pedagogical methodologies, we as instructors of math, engineering, and computer science courses discussed creating an inclusive project for students in a mathematics class. The topic of computational resource competition among smart devices and apps is selected since this prevalent problem is experienced by the general public, its fundamental mechanism is relevant to computing concepts studied in the target math class, and the physical setup for simulating this real-world problem through the form of game play is feasible with the available software and hardware resources used in other computing classes in the department. Details of project idea, classroom implementation, assessment results, and conclusions are introduced in the rest of the paper.

METHODS

Project Idea and Modifications

Background Information

The project idea arose during our discussion on a real-world problem to be incorporated in teaching a Calculus class. We consider that the experience of resource competition on smart devices is prevalent among students in the class, especially during remote classes when they need to access Zoom meetings on computers connected to multiple smart devices with various applications running at the same time. Students mentioned that their internet is excellent but sometimes due to unknown reasons the communication quality is disturbed. It is possible that multiple devices connected to their computers (security cameras, doorbells, heaters, air conditioners, washers, dryers, water kettles, smartwatches, Bluetooth speakers, TVs, etc.,) are competing for limited computational resources on the motherboard. The resource allocation process executed by the computer system is based on priority, i.e., the application request with higher priority gets served earlier (Tanenbaum 2023). The concept of priority is related to the math topics introduced in a Calculus class. Thus, we anticipate that this problem would stimulate students' curiosity and motivate them to track down the root cause while gaining thorough understanding of those math topics. To make the learning process more experiential and interactive, we incorporate game play in this project through computer programmable hardware emulation to allow students to express the priority concept as math formulas in software program and to observe their program outcome in a physical setting by playing switch flipping game with teammates to imitate the resource competition scenario.

Math Concept

In modern computer operating systems, processors handle resource allocation requests from different users based on their priority. For example, a program generating a notification of low battery level or virus detection has higher priority than a program showing daily news or weather information. The request with higher priority gets served earlier. There are different criteria to measure priority. One criteria relatively easy to apprehend is to use the derivative of the request data rate, i.e. the frequency of requests from one user, for the computer to make decision on resource allocation.

The Derivative is a fundamental math topic taught in the Calculus class. Consider the scenario with two users (devices or apps) competing for communication on a smartphone (let us say, Bluetooth connection with a smartwatch and running the Zoom app). Their requests are sent via two communication channels with limited data rates according to the functions, respectively:

$$f_1(x) = \frac{1+sinx}{2} \text{ and } f_2(x) = \frac{1+sin(2x-\frac{\pi}{6})}{2} \quad (1),(2)$$

When the value of $f_1(x) + f_2(x)$ exceeds 1, which is 100% of the data rate capacity, the users begin competing. Since the actual data transfer cannot exceed 1, the transfer follows the function

$$D(x) = min\{1, (f_1 + f_2)(x)\} \quad (3)$$

When competition occurs, the winning user with higher priority is identified, in this case it refers to the data rate function with a larger derivative (sudden increment of data amount within a time window). If at a given time x, it happens that the sum of values $(f_1 + f_2)(x) \leq 1$ then both requests are sent without interruption. However, if at a given time x, the sum of values $(f_1 + f_2)(x) > 1$ then the following selection criterion is applied:

$$S(x) = \begin{cases} f_1(x), if\,(f_1 - f_2)'(x) > 0, \\ f_2(x), if\,(f_1 - f_2)'(x) \leq 0 \end{cases} \tag{4}$$

Based on this math concept, we formulate the following initial assignments in the project to familiarize students with the issue of competing user devices/apps:

a) Use software to sketch the graph of the function $D(x) = min\,\{1, (f_1 + f_2)(x)\}$ modeling data usage by two user devices.
b) On the graph of $D(x)$ mark in red the intervals where the data from f_1 is transferred and in blue where the data from f_2 is transferred.
c) Compare the priority using the data rate derivative of the first user (smartwatch) in comparison to the second user (Zoom app). Do you think that designing the priority this way will cause disruptions while using Zoom? Do you think that this will cause disruptions while using a smartwatch?
d) Describe the functions that model the delays on each device.
e) How would you modify this priority to match the needs of the users in a better way?

Figure 1 shows a sample graph of the functions $(f_1 + f_2)(x)$ and $D(x)$. The unsent data is accumulated where $(f_1 + f_2)(x) > 1$, which is marked with a red color.

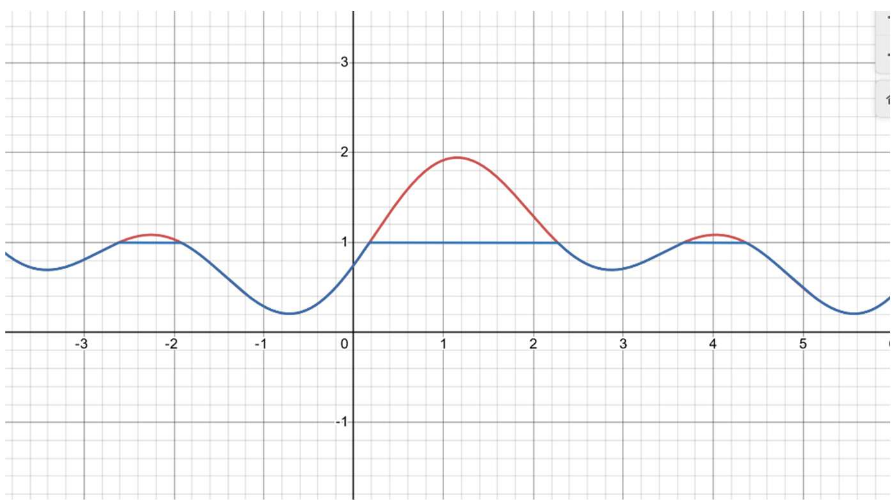

Figure 1. Graphs of the functions $(f_1 + f_2)(x)$ and $D(x)$.

Hardware Emulation

The second part of the project is to embody the math concept of derivatives in a software program, and allow the students to observe their program outcome on the hardware device with input/output interfaces on the motherboard The hardware device used to imitate the communication resource competition scenario is the Terasic DE1 System on a Chip (SoC) evaluation board embedded with Altera Cyclone V FPGA and ARM Cortex-A9 processor (Terasic 2025). Microsoft Windows XP or later with 64-bit OS and Quartus II software development environment are required to compile projects for DE1-SoC. A common programming language used to configure the FPGA to represent the logic relation between input and output interfaces is Verilog. This programmable hardware device offers a convenient and flexible means to achieve the goal of providing students with immersive experience of understanding the mathematical concept of derivatives, through interacting with the integrated interfaces on the circuit board, including switches, buttons, and LED lights. Its integrated interfaces and layout can be observed from Figure 2.

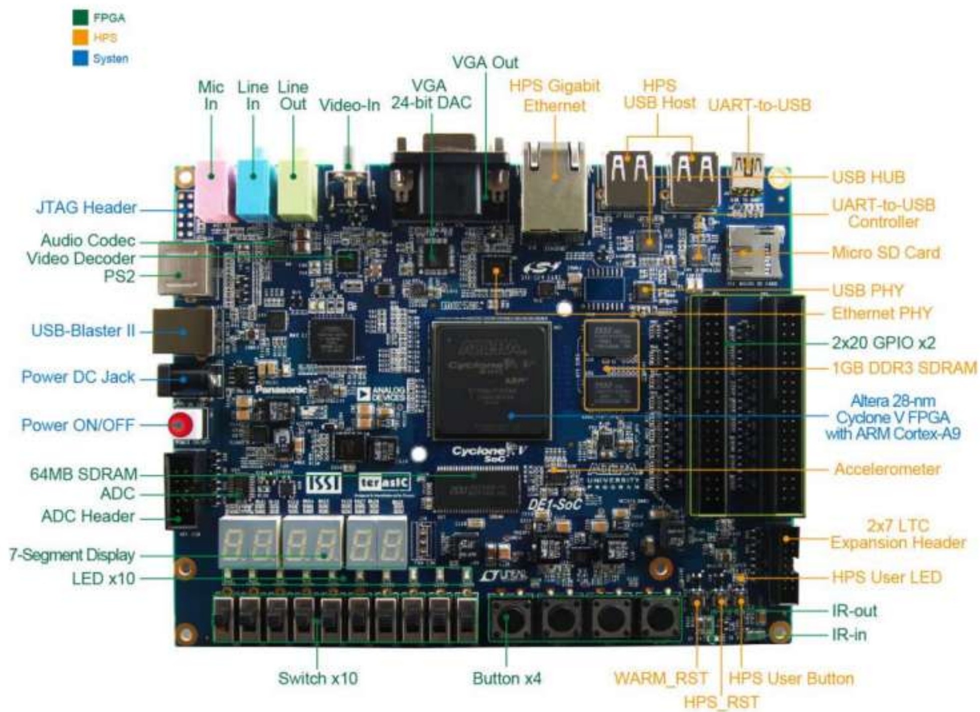

Fig. 2 Terasic DE1-SoC evaluation board.

To support program outcome observation through the form of game play, we choose two switches on the circuit board (bottom left side) as the communication channels for two competing users. The software program is designed in a way that an LED light above the switch with the higher flipping rate will turn on, and the LED light above the other switch will turn off. The flipping rate is an imitation of data rate, and the derivative of this switch flipping rate is calculated as the increased number of flipping actions at the current time unit duration (one second) from the previous one. When the program is executed on the circuit board, two students flip the switches to compete for the light and gain the impression of how the change of derivative affects the winning status.

Classroom Implementation

To implement this project in the Calculus class, we had students interact with each other during an icebreaker activity at the beginning of the semester, study the topic of derivatives in the third week, and after that conduct group work on hardware emulation and game play, followed by a survey on their project experience.

Icebreaker

The encouragement of classroom camaraderie began on the first day of the semester, when students introduce themselves. Depending on the size of the class, the activity can be performed in small groups or within the entire class. Students respond to the following questionnaire following the group conversation:

1. How shall we address you (your name or nickname)
2. Your culture and identity (how do you define yourself, where you are from, what languages you speak, what is in your mind, what are your passions)
3. Your college identity (Your major and classes you are taking this semester)
4. Your personal and/or professional goals for next week, next month, and next year.
5. What are your strengths and weaknesses:

math skills	EXCELLENT	AVERAGE	POOR
writing skills	EXCELLENT	AVERAGE	POOR
public speaking	EXCELLENT	AVERAGE	POOR
collaborative skills	EXCELLENT	AVERAGE	POOR
other skills (name them)			
	EXCELLENT	AVERAGE	POOR

6. Optional: what did you do over the weekend?
7. What similarities did you observe among the classmates?
8. Did you enjoy this activity?

After students introduced themselves, they answered questions about the similarities they found within the classroom. As time passed, a sense of community naturally emerged among them. Many came from Hispanic backgrounds, bringing a shared cultural richness to the classroom. A large portion pursued degrees in computer science, engineering, or applied mathematics, driven by a curiosity for problem-solving and innovation. Outside of the college, many students balance jobs and family duties, adding a layer of discipline and time management to their daily routines. Weekends often follow a familiar rhythm – some unwound by playing soccer, a passion that connect them beyond the classroom.

Through icebreaker activities, students uncovered surprising connections with their classmates. They discovered that someone they had just met was from the same country or that they shared multiple courses. Others realized they spoke the same language or had similar weekend routines – whether working a shift or playing a soccer game. These small but meaningful connections created a sense of belonging within the group. Friendships took root, making collaboration more natural and discussions more engaging. The classroom, once just a space for learning, transformed into a supportive environment where students not only grew academically but also built relationships that enriched their journey.

Classroom Teaching

The topic of derivatives is introduced in the third week of the semester, following the topics of limits and asymptotes. After presenting the formal definition, the math instructor explained the geometric interpretation of derivative to help students visualize the concept. This led to an in-class discussion where students explored the idea of incremental change – how a function responds to an infinitesimally small change in time. To reinforce their understanding, students were asked to share both mathematical and real-world examples that resonate with them. These included sudden changes in mood, abrupt spikes in blood pressure or other vital signs, sharp voltage shifts in a circuit, or rapid temperature fluctuations in a room.

Following this discussion, the instructor from computer engineering discipline introduced the Terasic DE1 SoC evaluation board to the class, sparking curiosity and enthusiasm. Students asked about the connection between derivatives and the programming aspects of the activity, gaining valuable interdisciplinary insight. They had the opportunity to examine the motherboard up close, and their excitement was evident, especially among the computer science students, who could barely contain their enthusiasm. After this classroom activity, students filled a presurvey designed to gauge their interest in STEM discipline (Appendix: Pre-survey on interest in math and technology).

Experiment

After the introduction on math theory and hardware information, students visited a computer lab to conduct experiment on hardware emulation. To familiarize students with hardware development, a sample Verilog program was introduced as a tutorial for students to study hardware control. Afterwards they worked in groups of two or three to modify the sample program and implement the derivative-based resource allocation algorithm described in the previous section Equation (2):

a) Look up the Terasic DE1 user manual, and find out the supported clock frequency, its signal name and pin number used in FPGA program. Also specify the signal names and pin numbers of on-board LED lights and switches.
b) Follow the video tutorial to create a HelloWorld FPGA project
   - My First FPGA Tutorial, Part 1, https://www.youtube.com/watch?v=5R5Tw_zSKZM
   - My First FPGA Tutorial, Part 2, https://www.youtube.com/watch?v=qrWP2IsD9w0
c) Modify the Verilog program in the example to detect the pulses generated by two switches and to turn on the light representing the switch with higher increase in the number of pulses detected in two consecutive seconds, using a clock of 50 MHz. Choose two LED lights on the device to represent the winning status, i.e., the light above the selected switch turns on while the other light turns off.
d) Flip the two switches to compete for the light. Observe the relation between the pattern of flipping action and the light status.

Figure 3. Activity in the lab

Figure 3 captures students in the computer lab, working collaboratively in pairs or small groups of three. The post-survey was proctored immediately after the activity to gather their reflections and insights (Appendix: Post-survey on interest in math and technology).

RESULTS

Informal Assessment

Beyond formal evaluations, the instructor's keen observations play a crucial role in assessing student engagement, not just academic understanding, but also the dynamics of involvement, interactions, collaboration, and confidence.

When the activity was introduced, students were eager to try it out. All students showed enthusiasm before and during the activity, but students majoring in computer science appeared particularly delighted while inspecting and touching the Terasic DE1-SoC evaluation board displayed to them in class. During the activity in the computer lab, students appeared peaceful and focused. While working in groups they demonstrated a spirit of teamwork, collaborating smoothly and harmoniously. These informal assessments, though unstructured, offer invaluable insights into the learning experience, painting a fuller picture of student growth beyond measurable outcomes.

Formal Assessment

The survey used the Likert scale with five levels (from left to right): agree, somehow agree, neutral, somehow disagree, disagree. It is important to recall that the Likert scales can be subject to response bias, where respondents may agree or disagree with all the statements. The scale layout can also affect response bias, with respondents tending to choose options on the left side of the scale or at the top of the scale (Likert 2025). All questions are included in the appendix.

The class consisted of 15 males and one female. The data reveals that the Asian/Pacific Islander and Hispanic groups have the highest representation, with 6 students each. All other ethnic categories have 1 student represented.

The answers to the second question summarize the distribution of students across four academic majors, indicating their respective numbers. This data highlights that the Mechanical Engineering major has the highest enrollment of 7 students, while Business Administration has the lowest, with 1 student. Five students major in Computer Science and the female student is among them. Three students major in Electrical Engineering.

Twelve students participated in the pre- and post-survey. Answers to further questions are represented in the circular diagrams to display the fractions of students who agreed (blue), somehow agreed (red), were neutral (orange), somehow disagrees (green) or disagreed (purple) with the statements.

Results in Pre-survey

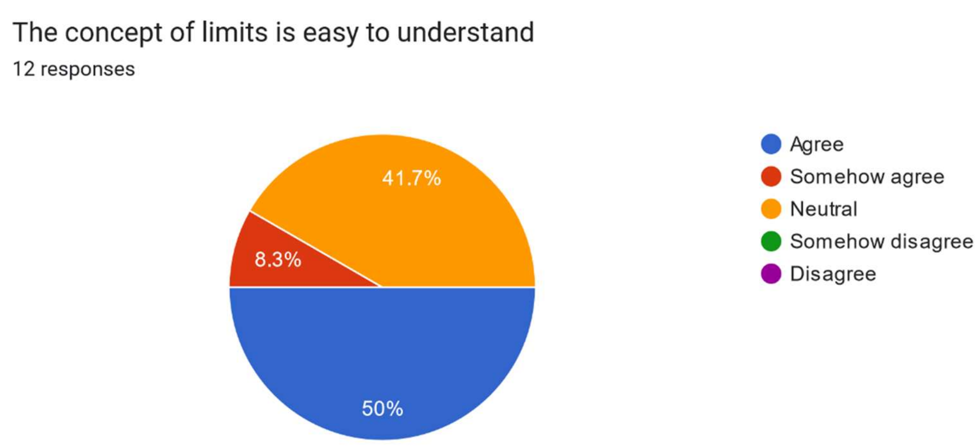

Figure 4. The concept of limits

The concept of limits, introduced at the beginning of the semester, appears to have become more accessible to students over time. Despite initial challenges, students now largely agree that limits are relatively straightforward to understand. Notably, there were no dissenting views regarding the statement that "limits are easy to understand," suggesting a consensus within the class. This likely reflects the effectiveness of teaching methods, practice opportunities, and the cumulative nature of learning foundational mathematical concepts.

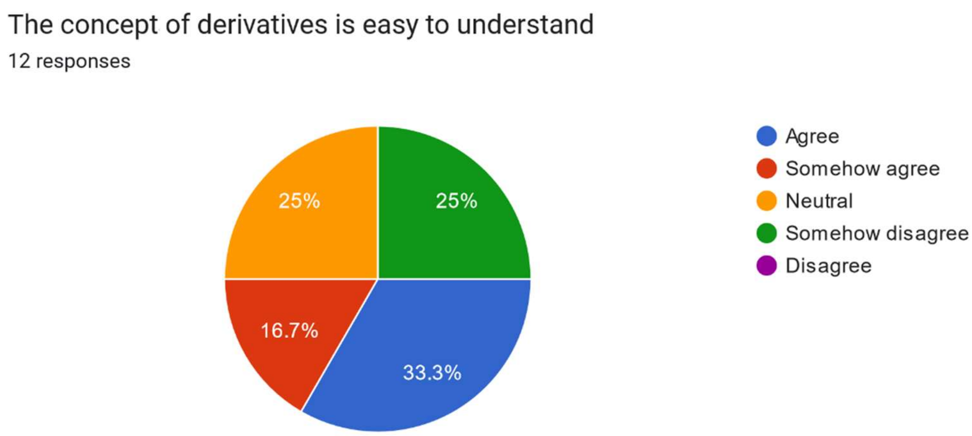

Figure 5. Concept of derivatives

In contrast, the concept of derivatives, introduced more recently, has elicited a broader range of opinions regarding its level of difficulty. Approximately 25% of students indicated that they do not find derivatives "easy to understand," yet no one expressed a strong disagreement. This variability may reflect the newness of the topic and students' differing levels of comfort and familiarity with applying derivatives in problem-solving. It is reasonable to expect that, as with limits, students' perceptions may shift toward greater ease of understanding as they gain more experience with the topic.

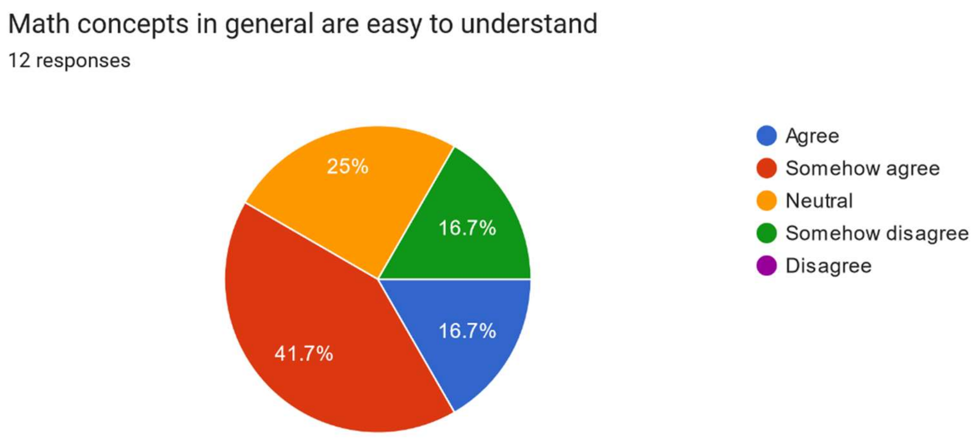

Figure 6. Math concepts in general

When considering mathematics concepts in general, the trend mirrors the discussion of derivatives, with some students expressing a moderate level of difficulty while others display more confidence. This pattern suggests that student perceptions are influenced not only by the complexity of the material but also by their familiarity with specific topics and their confidence in applying them in various contexts. As the semester progresses, these judgments may align more closely, particularly if reinforced by continued practice and targeted instructional support.

Results in Post-survey

Students' perception of the activity somehow resembles their perception of mathematical concept with one student expressing his strong opinion (disagree).

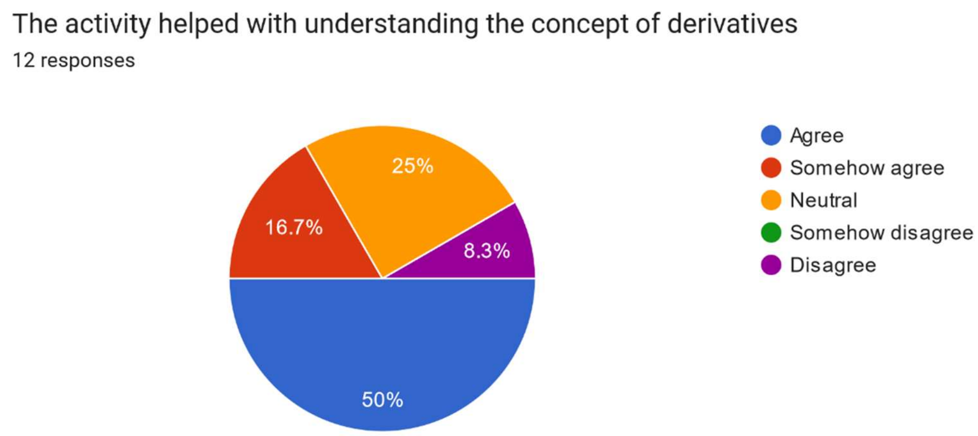

Figure 7. Effectiveness of the activity for explaining derivatives

While most students remained positive or neutral about the effectiveness of the activity, one person was in strong disagreement with that statement. He justified his statement by answering in the follow up question that he did not see any connection between math concepts.

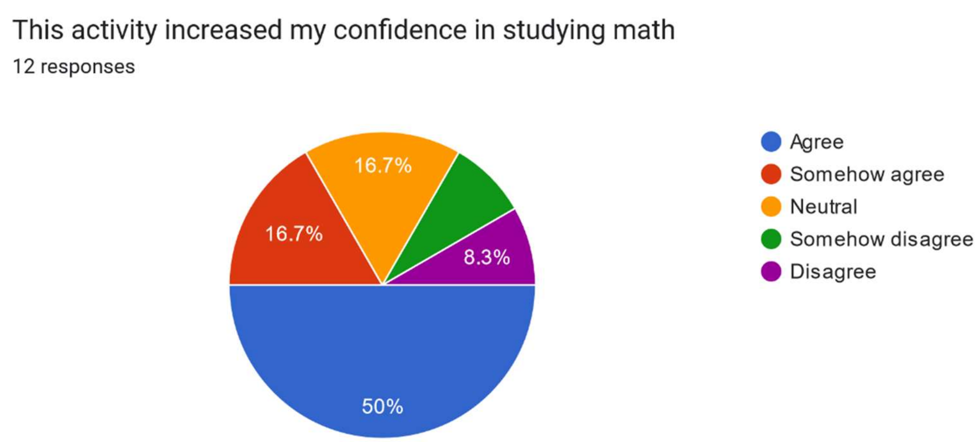

Figure 8. Self-confidence

Based on the students' responses, the activity had an uneven influence on their confidence in studying mathematics, while a vast majority of the students agreed with the statement, two students disagreed. One student justified his statement by saying "I don't understand how the activity uses derivatives" and the other "I don't see any connection between math concepts." Both students expressed their interest in "knowing how math examples are related in field of technology" and seeing "real world applications".

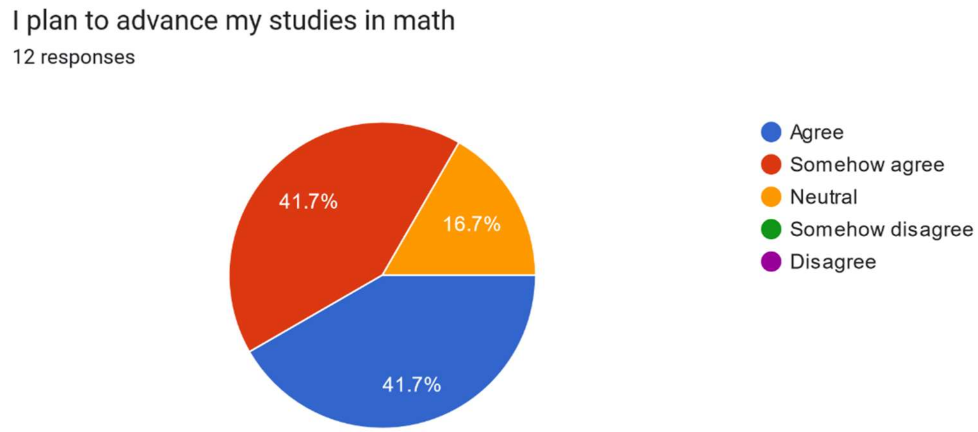

Figure 9. Interest in math

A vast majority of students are planning to advance in their studies in mathematics, regardless of their major, this is a requirement of their academic programs. However, they are interested in advancing their studies in technology as well, even if this may not be related to their major:

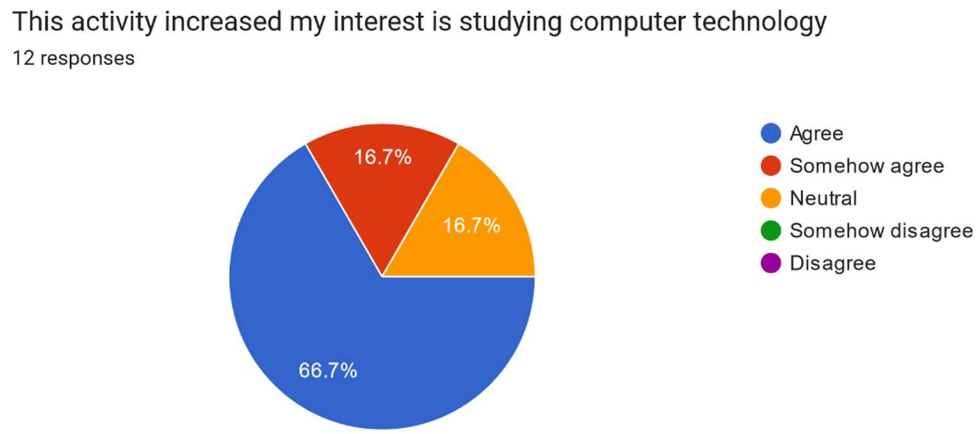

Figure 10. Interest in technology

DISCUSSION

Written Reflection

Students' long answers to the last question in the pre-survey ("Do you wish to advance your study in math and technology?") are displayed in Table 1 below. Students' responses vary in length, motivations. and reasoning.

I wish to advance my study in math.
Yes
Yes because it is required for my degree.
Even though math is challenging, technology has always been an Interest of mine so I'll do my best to advance my studies.
Yes, although my math is not very good though, I love the concept of math and enjoy it very much, which makes me wanna try my best in the class even if i struggle so much im willing to understand and pass my math classes.
Yes, I do because it is required for my field of study.
Yeah i do want to advance my study in math and technology because i think it will help with my major which is computer science.
Yes I want to make my math strong
I am not sure right now but may be in the future i will decide
Yes. As, there is a lot of scopes in this field with Elon musk surprising us with his new advanced technology I think there is a lot more possibilities in tech than the current situation .
Yes because I love the subject and want to learn more
I would want to learn more about technology and how to use it to the best of it's ability.

Table 1. Display of students' writing in the pre-survey (original spelling and grammar)

In the post-survey, a majority of the students (about 85% of those who completed the second survey) indicated that the activity helped with understanding the concepts of derivatives to some extent. Two students were neutral about it and nobody denied the statement. Students found physical interaction and gameplay more engaging and helpful than reading about the concepts. Table 2 displays students' writing (original spelling and grammar):

I liked physically interacting with the device.
Physical device is more easier or I feel more better with handling then math and examples.
I feel as if hands on and interacting with the device was more helpful since I was able to physically interact with the item and understand how it's works instead of being confused when reading a book about the device.

The activity helped students see how math is used in real-world applications. Interacting with the device made the concepts easier to understand and grasp
The activity helped students see how math is used in real-world applications. Interacting with the device made the concepts easier to understand and grasp.
Because outside of equations and number solving, you get to see how a certain concept is proved in real life.
This activity was fun and showed how math can be used in the real world.

Table 2. Display of students' writing in the post-survey (original spelling and grammar)

The activity provided visualization and contextual learning, which are often lacking in traditional reading-based approaches. At the same time students considered it to be more like a game, less like a lecture. They emphasized in the answer to the open-ended question that the gameplay aspect of the activity made learning more enjoyable and engaging compared to traditional learning. Students wrote:

> "It made it more fun and easier to understand in terms I can understand"

> "Interacting with the physical device through gameplay helps a lot in terms of understanding math concepts. It offers active engagement, visualization, motivation, contextual learning, feedback and adaptation. Reading can provide foundational knowledge and theoretical background but may lack the interactive elements that lead to a deeper understanding."

However, one student wrote

> "I don't understand how the activity uses derivatives."

Which suggests that the activity still needs some refinement. In particular in terms of logistics and scheduling. The lecture motivating the activity and introduction to the derivatives took place a few weeks before the actual lab visit, which created a certain disconnection among the topics.

The Story of the Female Student

In this class I have witnessed the very moment when the female student could fall or strive.

This student was returning to college after a five-year break and was understandably anxious about whether she could keep up in a math class. Her concerns proved valid at first. She struggled with arriving on time and maintaining focus during the two-hour sessions. However, after failing the first quiz, she began seeking advice on how to improve.

In my Calculus I course, I often discuss strategies with students for overcoming academic challenges. She listened closely, made changes, and worked diligently. She completed all the homework and quizzes, regularly sought help from tutors, and demonstrated genuine commitment.

Unfortunately, just before the final exam, she lost her job and asked to reschedule due to emotional stress. When we met to discuss math questions, it became clear to me that her focus was too scattered for her to do her best work. I shared my concern, and we mutually agreed she would take an Incomplete (INC) and defer the exam until after the winter break.

When we met again a few weeks later, she was a different person. She excitedly told me she had found a new job, which was better aligned with her major, in a healthier environment, and with a higher salary. She also shared how much she had disliked her previous job but hadn't realized how much it drained her until she lost it.

With renewed energy and focus, she took the final exam. When I calculated her scores, her course grade came out to a B. She was thrilled, since not only had she improved her job situation, but she also gained the confidence that she could succeed in college. We both knew that taking the exam earlier, under stress, would likely have resulted in a much lower grade.

CONCLUSIONS

This study highlights the effectiveness of integrating game play into an inclusive computing project in Calculus class that connects mathematical theory with real-world applications. By engaging students in designing and analyzing priority criteria in resource allocation for competing smart devices, we provided an interdisciplinary learning experience that deepened their understanding of derivatives and their applications in technology. The combination of structured classroom interventions, interactive lab activities, and hardware emulation helped foster a more inclusive learning environment, particularly for underrepresented students in STEM.

Student feedback and survey results indicate that in general the project increased engagement, confidence, and interest in both mathematics and technology. Many students found the hands-on interaction with physical devices more intuitive and engaging than traditional lecture-based approaches. The use of collaborative activities also contributed to a stronger sense of community in the classroom, further promoting inclusivity.

Despite these successes, challenges remain. The scheduling gap between introducing derivatives in lectures and the hands-on lab experience created a disconnect that affected some students' comprehension. Additionally, while most students saw clear connections between mathematics and technology, a few struggled to grasp the relevance of derivatives within the activity. Addressing these issues through improved scheduling, clearer instructional scaffolding, and additional examples of real-world applications will enhance the effectiveness of future implementations.

Overall, this study underscores the value of interdisciplinary, project-based learning in fostering both mathematical understanding and a sense of belonging in STEM education. By refining our approach and continuing to prioritize inclusivity, we can create learning environments that better support all students in their academic and professional journeys.

Students generally found that interacting with the physical device made the math concepts easier to understand, more engaging, and more relevant to real-world applications. The interactive and visual nature of the activity facilitated a deeper understanding compared to traditional reading-based or lecture-based approaches. Thus, the mathematics classroom became more inclusive by addressing students' needs and sparking their interest and involvement in the topic of derivatives.

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APPENDIX: PRE-SURVEY AND POST-SURVEY

Pre-survey on interest in math and technology

Name: Date:

1. Gender: Female Male Other

2. Ethnicity:
    a. American Indian or Alaskan Native
    b. Asian / Pacific Islander
    c. Black or African American
    d. Hispanic
    e. White / Caucasian
    f. Multiple ethnicity/ Other

3. Major:

4. The concept of derivatives is easy to understand
   Agree Somehow Agree Neutral Somehow disagree Disagree

5. The concept of limits is easy to understand
   Agree Somehow Agree Neutral Somehow disagree Disagree

6. Math concepts in general are easy to understand
   Agree Somehow Agree Neutral Somehow disagree Disagree

7. Do you see the necessity or applications of math in your field of study? Explain.

8. Do you use computers or technology for fun? Explain.

9. Do you know examples of math in computers or technology? Explain

10. Do you wish to further advance your study in math and technology? Explain

Post-survey on interest in math and technology

Name: Date:

1. Gender: Female Male Other

2. Ethnicity:
   a. American Indian or Alaskan Native
   b. Asian / Pacific Islander
   c. Black or African American
   d. Hispanic
   e. White / Caucasian
   f. Multiple ethnicity/ Other

3. Major:
4. The activity helped with understanding the concepts of derivatives

   Agree Somehow Agree Neutral Somehow disagree Disagree

5. This activity increased your confidence in studying math

   Agree Somehow Agree Neutral Somehow disagree Disagree

6. I plan to advance my studies in math
   Agree Somehow Agree Neutral Somehow disagree Disagree

7. This activity increased my interest is studying computer technology
   Agree Somehow Agree Neutral Somehow disagree Disagree

8. I wish for more example of using math in technology. Explain

9. How do you consider the difference between reading about these examples and interacting with the physical device through game play, in terms of helping to understand the math concept? Explain

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Metacognitive Discourse Forums as a Way to Engage Biology and STEM Students in Meaningful Discussions

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Abstract: The rapidly evolving educational landscape allows, and often demands, the integration of innovative digital approaches into the curriculum. Whether the course is conducted in-person, online, or hyflex, synchronous or asynchronous, the wide range of available digital tools and platforms now offer multi-faceted learning experiences designed to actively engage students. In our biology classes, we used Metacognitive Discourse Forum (MDF), an approach to collective annotation on an assignment, which may help students develop critical thinking, metacognitive skills, and improve academic performance. The article describes the utilization of MDF in our classes and discusses its potential impact for enhancing STEM teaching and learning.

Keywords: metacognition, discourse, Biology, STEM, social annotations

INTRODUCTION

Designed to improve metacognitive skills in STEM learning, Metacognitive Discourse Forums (MDF) is an andragogical approach that we used for interactive online discussions and student social annotations. It enables collective engagement with the course materials, which are visible to all peers and the instructor, fostering reflection and responses to other participants' contributions.

Metacognition involves the ability to reflect on one's thinking processes, and MDF provides space for students to engage in metacognitive practices (Pennequin et al., 2010; Alifiani et al., 2023). In MDF, students not only share their thoughts and ideas about their learning but also use annotations, which have been shown to strengthen students' critical thinking abilities (Johnson et al., 2010; Hwang et al., 2007). These discussions are not limited to text, but can also incorporate video content, offering an additional modality for learning. Students can ask questions, seek feedback from their peers and the instructor, and engage in discussions to improve their understanding of the course material. This approach helps students become aware of their learning processes, identify their strengths and weaknesses, and develop effective strategies for improving their learning experience.

In contrast to traditional discussion boards commonly built into learning management systems, such as Blackboard or Brightspace, where students are typically expected to read or view materials before reflecting on them, MDF offers the distinct advantage of capturing the “aha” moment. MDF enables students to comment in real time on the assignments or videos as they engage with them. As students view each other’s comments, the learning experience becomes more dynamic, collaborative, and interactive.

MDF can be implemented in a variety of ways to support student learning. They can support students' learning of specific content, help them develop critical thinking skills, or support their overall academic success. MDF can also promote a sense of a learning community and psychological safety for students (Fridman et al., 2025). The approach involves social annotations of readings and video content, followed by intra- and inter-group metacognitive discourse focused on the epistemology of the learner. This process enhances both subject-specific learning and the development of metacognitive awareness.

LITERATURE REVIEW

Academic research emphasizes that students are more likely to continue engaging in metacognitive activities in problem-solving when they understand their value and purpose; this is known as "informed" training, which is more effective than "blind" training (Lin, 2001; Brown et al., 1983). The term "metacognitive discourse forum" refers to structured conversations or reflections where individuals think and talk about their own thinking and learning processes. This kind of dialogue helps learners become more aware of how they learn, adjust, and develop better strategies. Dr. Burkart created an assignment that deliberately engaged students in metacognitive discourse by requiring them to reflect on and articulate: past learning struggles, reasons for focusing on specific topics, strategies they tried and learned, outcomes, and recommendations for others. This allowed students not just to do metacognition (thinking about their thinking), but to talk about it—hence, “metacognitive discourse.” It reinforced deeper learning by encouraging students to process and express their growth interactively (Burkart, 2022). Garrison and Akyol (2013) talk about the online discussion boards in online learning environments, wherein instructors have prompted students to engage in reflective forums where they must not only respond to content but also reflect on how their understanding evolved, what strategies they used, and what they found challenging. These forums promote both cognitive presence and metacognitive awareness.

Metacognitive Discourse Forums, at their core, use reading and writing to represent a form of social interaction, serving as a dialogue between the author and the viewer/reader and the peers. Students can express this social aspect by annotating, which involves posting questions, leaving comments, cross-referencing external sources, and employing various other techniques to interact with text and video content. Social annotations, in turn, evolve, consolidating the annotations of a collective group. The advent of digital platforms has facilitated this process, enabling all students in a group to annotate shared content collaboratively. In STEM courses, we can tackle reading as a forum for communication that hinges on actively engaging with diverse perspectives to grasp the content fully. Social annotation serves as a channel for such communication, uniting the voices of all students in a group and promoting comprehension of the subject matter.

Previous studies showed the positive impact of social annotations. For example, Johnson et al. (2010) and Hwang et al. (2007) found that, compared to students who did not conduct social annotation activities, the students who conducted social annotation experienced improved metacognitive, critical thinking, and reading comprehension skills. Razon et al. (2011) compared 40 graduate students' comprehension and retention of course content using HyLighter, an online social annotation tool, and using paper highlights. They found that the students who used HyLighter better understood the course content than those who annotated on paper. Gao (2013) found that, out of a group of 122 undergraduate pre-service student teachers, the majority of the students left more comments during an annotation activity than they had to, and that the majority reported having a positive experience using the social annotation activity to learn their course content.

Aguillon and Monterola (2020) examined the influence of Web 2.0 technology, specifically online collaborative video annotation (OCVA), on the reflective thinking and academic self-discipline of STEM students. Their investigation revealed that while OCVA did not significantly impact overall reflective thinking, it influenced the component of understanding in the reflective thinking process. Moreover, this innovative learning approach positively affected habitual action and academic self-discipline, specifically among low-performing students in STEM and in General Chemistry 1. These studies underscore the intricate relationship between technology-enhanced learning and metacognitive processes, signifying how students engage with and benefit from multimedia resources in the contemporary educational landscape.

Tanner emphasizes integrating metacognition into undergraduate biology education to help students think like biologists and further suggests explicit teaching of metacognitive strategies, creating a classroom culture that encourages reflection and sharing of confusion, and modeling metacognition by instructors. Examples include prompting students to ask self-questions about their learning process, integrating reflection into assignments, and demonstrating problem-solving approaches (Tanner, 2012).

In learning activities, metacognition can be assessed through targeted instruction that prompts students to reflect on their cognitive processes (Lai, 2011). Metacognitive interventions serve as practical tools in activating these processes. One such intervention involves using metacognitive questions, segmented into categories including comprehension, connection, strategic, and reflection questions (Özcan & Erktin, 2015). As Faradiba et al. (2019) highlighted, comprehension questions facilitate students' grasp of concepts, while connection questions encourage them to establish links between the current topic and previously encountered concepts. Strategic questions aid students in determining the most efficient approach to address biological inquiries or challenges. Lastly, reflection questions prompt students to assess the methodologies employed in addressing questions and evaluating their responses (Alifiani et al., 2023).

METHODS

In this study, we used a qualitative approach to explore how the Metacognitive Discourse Forums were used to assist students in solving population genetics problems in General Biology II at Kingsborough Community College, Brooklyn, The City University of New York. This research falls under exploratory descriptive categorization. It aims at determining the outcomes of using metacognitive discourse forums with students solving Population Genetics problems in Biology. The data was primarily collected through the Metacognitive Discourse Forums conducted with students, while they solved population genetics problems to determine the allele frequencies by applying the Hardy-Weinberg Theorem.

The investigation commenced with a cohort of 37 students enrolled in General Biology II. The instructional sessions spanned over three meetings, during which all student activities and interactions were observed and documented. The methodology and educational interventions applied throughout these sessions are detailed in Table 2. The number and structure of these sessions can be modified according to the modality of the class. In this class, students were encouraged to complete MDF before attempting to solve the population genetics problems assigned. Although using MDF was strongly encouraged, it was not mandatory.

The framework of metacognitive questions utilized during the MDFs and the follow-up in-person meetings, which facilitated the metacognitive intervention, is outlined in Table 1.

Types of Metacognitive Questions	**Metacognitive Questions**
Comprehension Question	1)What is the material related to this problem? 2) Can you show the allele frequencies that you are looking for?

Connection Question	1) Did you immediately solve this problem in the same way as you did before? 2) What are the differences between this question and the questions you have done before? 3)Have you ever worked on questions like this before?
Strategic Question	1) What strategies can be used to solve the problem? 2) Why is this considered the right strategy? 3) What is the Hardy-Weinberg Theorem?
Reflection Question	1) Is the process correct? 2) Does the solution make sense? 3) Is there any other way to solve this problem? 4) What did you find confusing?

Table 1: The Metacognitive Questions. Inspired by (Tanner, 2012).

Meeting 1	**Meeting 2**	**Meeting 3**
Objective: Topic introduction, assess students prior knowledge on the topic. Provide instructions to students on the MDF completion, covering the What, When and How questions. Activity: In-person Laboratory lecture-discussion on Population genetics, Allele Frequencies and Hardy-Weinberg Principle, Theorem, Equilibrium, and Conditions. For homework, students were asked to participate in the MDF and solve four Population genetics problems to determine the Allele frequencies by applying the Hardy-Weinberg Theorem.	Objective: Instructor-led student engagement in MDF. Students show their understanding, critical thinking and reflection by asking and answering self, peer and instructor questions. Activity: Asynchronous online MDF on Hardy-Weinberg Principle, Theorem, Equilibrium, and Conditions. Solving the four population genetics problems.	Objective: Cover student misconceptions and verbal assessment of student's metacognitive skills. Activity: In-person laboratory lecture-discussion on the results and the solutions of the four Population Genetics problems and determining the allele frequencies using the Hardy-Weinberg Principle, Theorem, Equilibrium, and Conditions.

Table 2. Sequence of the Learning Activities.

The Lesson: Solving a Population Genetic Problem by the Hardy-Weinberg Theorem.

Direct evidence of an evolving population is a change in allele frequencies. The Hardy-Weinberg Theorem is one way to determine whether allele or genotype frequencies are changing from generation to generation. It states that alleles and genotype frequencies do not change from generation to generation under the following conditions. Most conditions (assumptions) are unmet in natural populations, so populations evolve (Brogun et al., 2021).

Changes in allele frequencies can be calculated based on the following equations:

$$p + q = 1 \tag{1}$$

p = frequency of dominant alleles in a population
q = frequency of recessive alleles in a population

Squaring both sides

$$(p + q)^2 = 1^2 \tag{2}$$

will yield:

$$p^2 + 2pq + q^2 = 1 \tag{3}$$

p^2 = frequency of homozygous dominant genotypes (individuals) in a population
q^2 = frequency of homozygous recessive genotypes (individuals) in a population
2pq = frequency of heterozygous genotypes (individuals) in a population

The conditions (assumptions) of the Hardy-Weinberg Equilibrium include: No mutations, random mating, no natural selection, extremely large population size, no gene flow, and no genetic drift.

Creating the Assignment That Incorporates Metacognitive Discourse Forums:

We created video lessons in Dropbox, embedded the videos in the Learning Management System, i.e. Blackboard or Brightspace, and assigned students to view the videos and make annotations in the LMS. Below is a description of how we implemented the Metacognitive Discourse Forum.

To set up the MDF, begin by creating a video that introduces the assigned reading materials and covers the critical points for the MDF. The video should include a voice-over narration summarizing the content, highlighting key concepts, and identifying critical points for discussion. Screen recording or video editing tools may be used to combine the narration with relevant slides or text excerpts to enhance clarity and engagement. Once complete, upload the video to a clearly labeled folder in Dropbox (e.g., "Metacognitive Discourse Forum Materials – [Date/Topic]").

Next, generate a shareable link to the video and copy the link. In the LMS, navigate to the appropriate course, create a new content item or module, and embed the Dropbox video link using the content editor. Ensure the video opens properly for students. Configure the link as a Content Provider, which will create a gradebook column to track participation.

It is important to include detailed instructions clearly outlining student expectations, such as the required number of annotations, peer replies, and instructor interactions needed for full credit. Sample student instructions are provided below:

1. Accessing the Forum:
    - Go to the Metacognitive Discourse Forum section in your LMS.
    - Click on the provided link to access the video recording.
2. Making Annotations:
    - While watching the video, make annotations and answer questions posted by the instructor.
    - Review the assigned reading materials and make annotations directly in the Metacognitive Discourse Forum within the LMS. You are required to make a minimum of [X] annotations on key points, answer questions, and raise questions related to the video or a reading.
    - Ensure your annotations are thoughtful and contribute to the discussion. Highlight important concepts and provide your perspective.
3. Responding to Peers:
    - Read and review annotations made by your peers. You are required to reply to at least [Y] peer annotations. Your replies should be constructive, engage with the content, and further the discussion.
    - When replying, provide thoughtful comments revealing your critical thinking, ask clarifying questions, or offer alternative perspectives.
4. Receiving Instructor Feedback:
    - Monitor the forum for responses from the instructor. The instructor will provide feedback on your annotations and participation.
    - Replies from the instructor will be available in the forum and may also be reflected in the gradebook column created through the Content Provider setup.
5. Grading and Feedback:
    - Points for annotations and peer interactions will be recorded in the LMS's gradebook, visible under the grading column.

- Ensure you meet all requirements for annotations and replies to receive full credit.

To make the most of the Metacognitive Discourse Forums, participants should regularly check the forum for updates and feedback, ensuring they stay informed and responsive. Active engagement is key; students are encouraged to contribute thoughtfully to discussions and respond meaningfully to their peers. By following these guidelines, both instructors and students can use the forums effectively to deepen their engagement with course materials and enhance overall learning.

RESULTS

In this study, the Metacognitive Discourse Forum was used to engage students in class content in a meaningful way. Students were presented with content in the form of video and text. Students were asked metacognitive questions that addressed the higher order of Bloom's taxonomy, including comprehension, strategy, connection, and reflection (Table 1), and were assigned to use social annotation tools. Figure 1 depicts examples of the student responses in MDF using the Dropbox platform with student-content, student-student, and student-instructor social annotations of the Instructor-narrated video of the assigned reading. Figure 1 includes screenshots from actual student responses. Figures 1a and b demonstrate a comprehension question (see Table 1) asked by the instructor, prompting students to think about the significance of the Hardy-Weinberg principle as it relates to evolution. Students paused the reading and video to think about what they were learning, and students' reflections are shown (Figures 1a and 1b). Likewise, in another example, students were asked a reflection question (Figure 1c and see Table 1). Students were asked to reflect on what they found most confusing in the Hardy-Weinberg Theorem. As seen in Figure 1c, most students found the allele frequency calculations confusing.

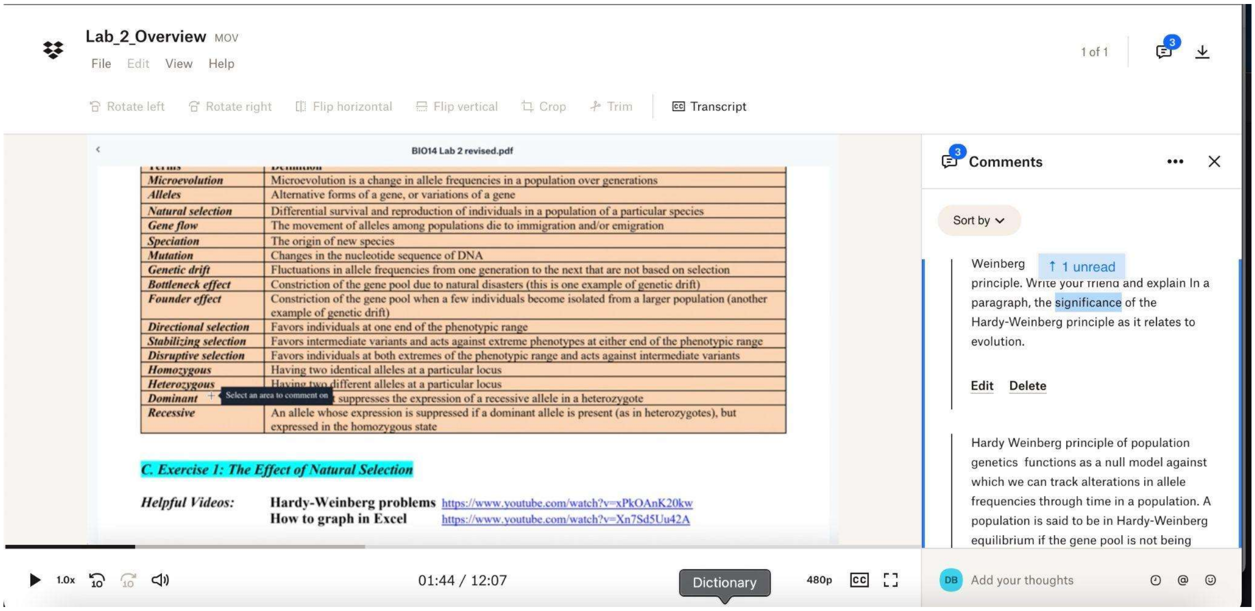

Figure 1a: Example of the student responses to MDF's Connection and Reflection questions (see Table 1).

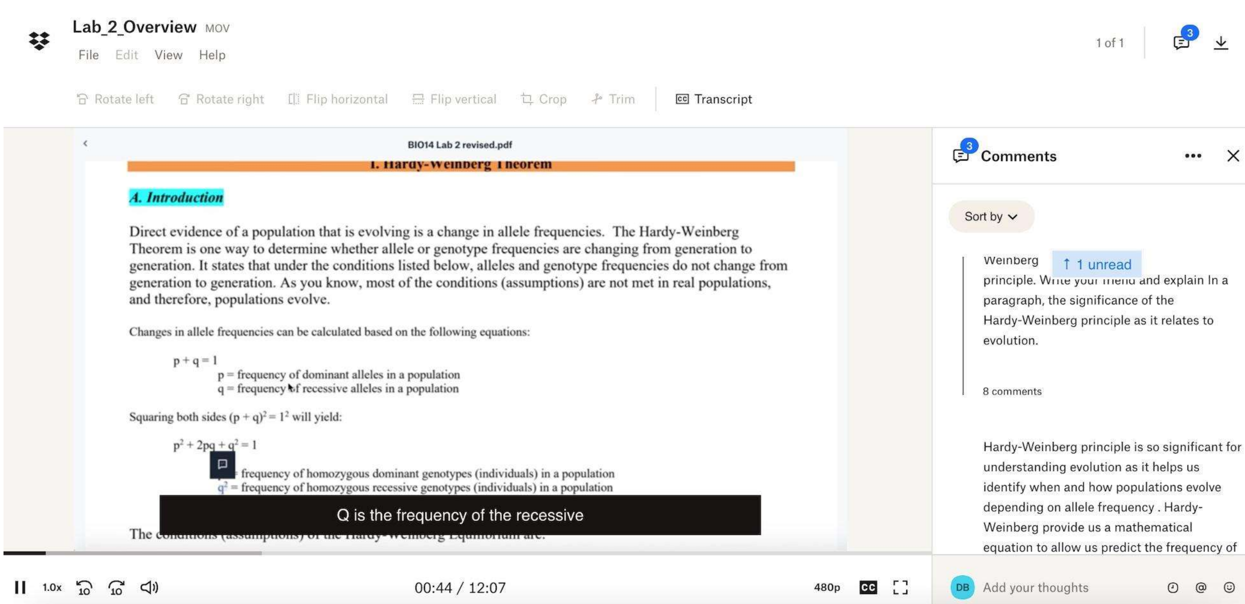

Figure 1b. Example of the student responses to the Strategic Questions in MDF (see Table 1).

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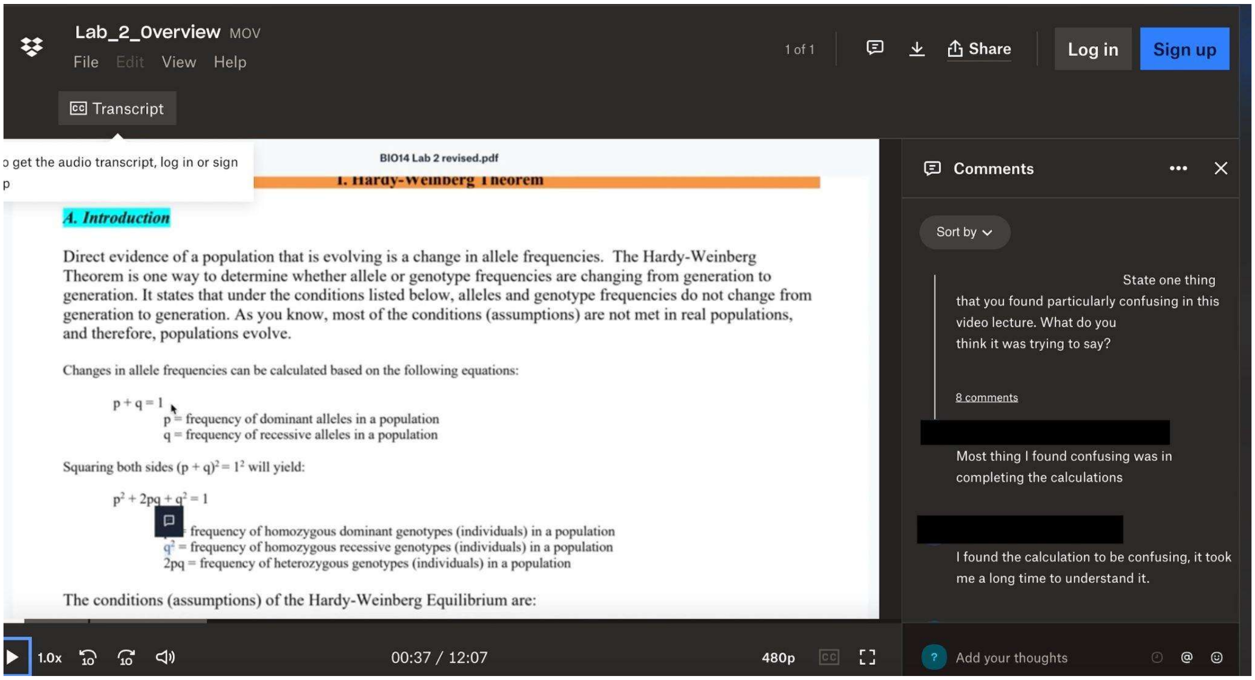
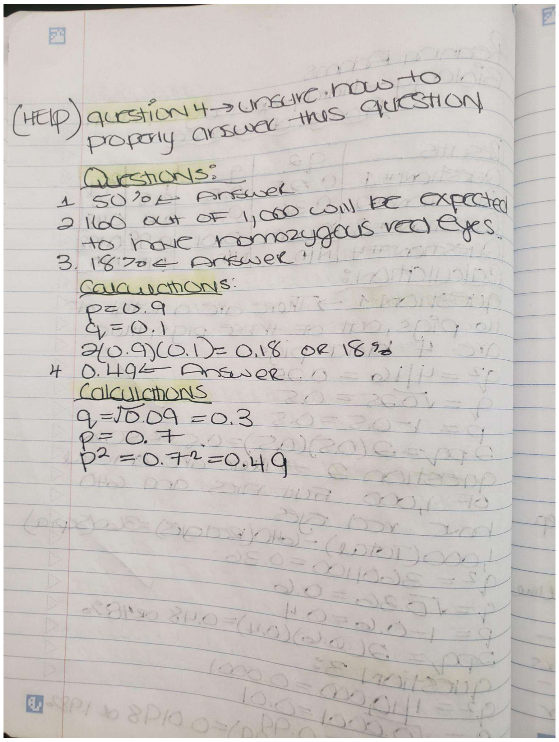


Figure 1c: Example of the student responses to Reflective Questions regarding confusion in MDF (see Table 1). Student names are blocked for viewing.

Students were asked to solve four population genetics problems to determine allele frequencies and then show calculations and the answers in their Lab Journals. Problem 1 asked them about a population of 16 pigs where the allele for a gray coat is recessive. Use the Hardy-Weinberg equation to determine the percentage of the pig population heterozygous for pink coats. Four gray coats and 12 pink coat pigs are in the population—a possible solution to Problem 1. The Hardy-Weinberg Theorem states that allele frequencies will remain constant from generation to generation if there is no selection, mutation, migration, or genetic drift in a population where mating is random.


(HELP) question 4 → unsure how to properly answer this question

Questions:

1 50% ← Answer
2 160 out of 1,000 will be expected to have homozygous red eyes.
3. 18% ← Answer

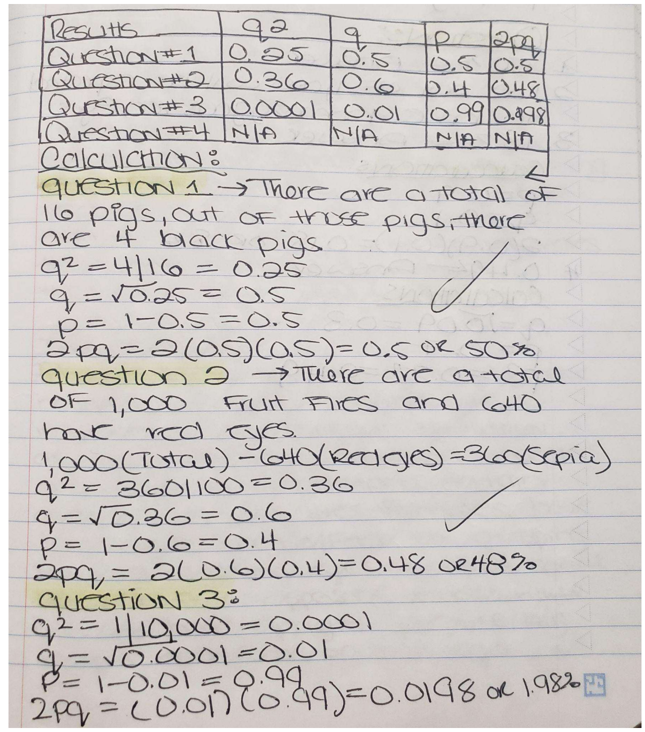
Calculations:

$p = 0.9$
$q = 0.1$
$2(0.9)(0.1) = 0.18$ or 18%

4 0.49 ← Answer

Calculations

$q = \sqrt{0.09} = 0.3$
$p = 0.7$
$p^2 = 0.7^2 = 0.49$



Results	q2	q	p	2pq
Question #1	0.25	0.5	0.5	0.5
Question #2	0.36	0.6	0.4	0.48
Question #3	0.0001	0.01	0.99	0.198
Question #4	N/A	N/A	N/A	N/A

Calculation:

Question 1 → There are a total of 16 pigs, out of those pigs, there are 4 black pigs

$q^2 = 4/16 = 0.25$
$q = \sqrt{0.25} = 0.5$
$p = 1 - 0.5 = 0.5$
$2pq = 2(0.5)(0.5) = 0.5$ or 50%

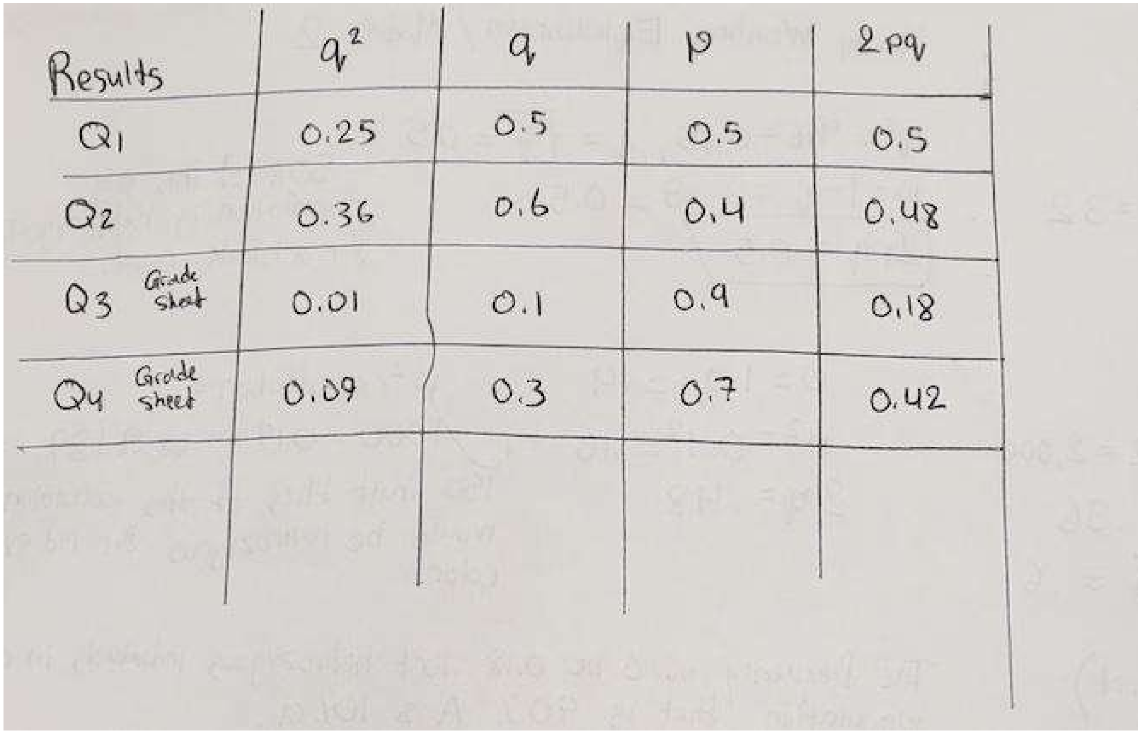
Question 2 → There are a total of 1,000 Fruit Flies and 640 have red eyes.

1,000 (Total) − 640 (Red eyes) = 360 (Sepia)
$q^2 = 360/100 = 0.36$
$q = \sqrt{0.36} = 0.6$
$p = 1 - 0.6 = 0.4$
$2pq = 2(0.6)(0.4) = 0.48$ or 48%

Question 3:

$q^2 = 1/10{,}000 = 0.0001$
$q = \sqrt{0.0001} = 0.01$
$p = 1 - 0.01 = 0.99$
$2pq = (0.01)(0.99) = 0.0198$ or 1.98%

Figure 2a: Student answers to the Population Genetics problems 1 through 4 who participated in MDF. On the left, the student’s initial response to the problems. On the right, students’ improved responses based on interaction with the instructor and peers via MDF.



Results	q^2	q	p	$2pq$
Q1	0.25	0.5	0.5	0.5
Q2	0.36	0.6	0.4	0.48
Q3 Grade sheet	0.01	0.1	0.9	0.18
Q4 Grade sheet	0.09	0.3	0.7	0.42

Figure 2b. Student answers to the Population Genetics problems 1 through 4 who did not participate in MDF.

For the Hardy-Weinberg Theorem and calculations, please see the methods section. As described in the methods section, completing MDF was strongly encouraged but optional. Two student examples are shown in Figure 2 as a representation of submissions from students who completed the MDF before attempting homework problems (2a) and students who did not complete the MDF (2b). Students who completed MDF showed their calculations and provided answers to the population genetics problems. When these students encountered confusion, they communicated these concerns to the instructor. Figure 2a shows a student's response before and after interacting with their instructor and peers. After the MDF intervention, the student was able to reflect and explain their understanding.

Furthermore, the instructor was able to assess what the students learned and what they were still lacking. In this example, this student was still having difficulty with question 4. Hence, this intervention also provides feedback to the instructor on what students are still struggling with and what could be addressed during meeting 3 (see Table 2). Conversely, students who did not engage with the MDF omitted their calculations in their submissions. While some of these answers were correct and others incorrect, there was no evidence for the instructor to assess the student's learning process or understanding.

Of the 37 students in this study, 17 engaged in the MDF annotations and successfully demonstrated their calculations for the four population genetics problems. However, three students made calculation errors in this group, leading to incorrect answers. Despite these initial mistakes, their underlying logic and calculation processes were clear and indicative of a correct conceptual understanding, but faulty execution. Remarkably, after participating in the in-person third session meeting, these students could self-identify and correct their calculation errors, showcasing an example of metacognition. This ability to reflect on and adjust their learning process highlights the significance of metacognitive strategies in academic success.

In contrast, only seven out of the 20 students who did not participate in the MDF managed to provide correct answers to the problems. We observed that all 20 students who bypassed the MDF engagement needed help articulating their problem-solving process or explaining how they arrived at their solutions to the four population genetics problems. This lack of self-awareness and inability to reflect on their thought processes underscores the essential role of metacognition in not just achieving correct outcomes but in developing a deeper, articulated understanding of the material. Engaging with MDF not only facilitates correct problem-solving but also potentially enhances students' metacognitive abilities, allowing them to better understand their learning processes.

Our findings demonstrated the potential effectiveness of MDF in improving students' metacognition, building connections among students and between students and instructors, and supporting students' learning in general. Here we demonstrate with examples how MDF helped students to pause and think about their learning and ask for help when they needed it.

DISCUSSION

STEM instructors look for ways to support students' learning and success in their field. Different approaches are used to achieve this; instructors look for ways to improve students' critical thinking, engagement, and metacognition. They also aim to provide a supportive classroom environment where students and instructors can interact freely and comfortably and find ways to quickly and effectively assess student learning. Although different tools and methods have been used, here we describe MDF as a tool that provides a space to achieve these goals all at once. In this study, we explored MDF to engage all students in class content via video and text format simultaneously and to pose metacognitive questions (see Table 1 for examples) to prompt students to monitor and evaluate their learning. In addition to presenting class materials and metacognition, MDF included social annotation. This type of metacognitive reflection helps students evaluate their own learning, and social annotation helps students to express their thinking, connect with their peers and their instructor, and ensure that the instructor can get instant feedback. The instructor then knows what to address during the class discussion.

An example of a potentially beneficial use of MDF is shown in this study. After an in-person discussion on population genetics, allele frequencies, and the Hardy-Weinberg Theorem (see Table 2), students were encouraged to participate in MDF and were assigned to solve four population genetics problems to determine the allele frequencies. Here, we used Dropbox as an MDF platform. To show their thinking and learning, students were asked metacognitive questions. The students who completed the MDF and actively participated in social annotation were able to show their thinking and work for solving the problems. They were able to evaluate their learning, identify their confusions, and ask for help from the instructor. They were also able to connect with their peers. For example, when the instructor asked about the most confusing part of this topic, most of the students identified calculations as the most challenging aspect (Figure 1c). This provides a support environment in class and instantly provides feedback to the instructor. On the other hand, students who did not complete the MDF could not express their thoughts. Although they may have given answers to the problems assigned, they demonstrated suspension of sense-making, not being able to express their thinking, the ways they solved the problems, or identify their confusions. Since these students did not complete the MDF and/or show any work in their assignment, the instructor cannot monitor students' learning or address confusion.

Our study supports previous literature and adds another dimension to support student learning. The positive impact of social annotation in text (Johnson et al., 2010; Hwang et al., 2007) and video (Aguillon and Monterola, 2020) formats has been demonstrated. Here, we use MDF to simultaneously incorporate social annotation in text and video formats. Integrating metacognition into STEM, and especially biology education, was shown to help students think like biologists (Tanner, 2012). Furthermore, targeted instruction effectively promoted metacognition (Lai, 2011). In this study, MDF showed a potential to be a platform where targeted instruction through metacognitive questions improved students' thinking and learning.

Instructors who are interested in using MDFs in the classroom should keep a few aspects in mind. First, they need to choose a forum platform appropriate for their students' needs. There are several different platforms available, so instructors can select one that is easy to use and that will allow tracking student participation. Second, the instructor must create a clear and concise learning objective for the MDF (see Table 2). Once the instructor has clear objectives, they can design activities and discussions that will help students achieve those objectives. Third, instructors need to guide students on how to participate in the MDF. This includes demonstrating how to use the forum platform, post thoughtful and constructive comments, and respond to the comments of others (Figure 1). Finally, instructors need to monitor the MDF and provide constructive feedback to students. This will help to ensure that students are using the forum effectively and that they are getting the most out of their participation. MDF can be a valuable tool for supporting student learning in biology and STEM. MDF may be a good option for the instructors who are looking for a way to help their students develop metacognitive skills, improve critical thinking skills, and increase academic achievement.

CONCLUSIONS

The study utilized Metacognitive Discourse Forums to address problem-solving challenges as part of the metacognitive intervention. These forums provided a platform for STEM students to engage in reflective dialogue, address cognitive gaps, and receive feedback on their problem-solving processes. Metacognitive support, including discussions in these forums, helped biology students move from procedural to more integrated conceptual understanding.

Educators should consider integrating Metacognitive Discourse Forums into their teaching and learning practices to promote deeper cognitive engagement and enhance learning flexibility. By incorporating these forums, educators can support a reflective, inclusive, and interactive learning environment where students engage in discussions that promote self-awareness, psychological safety, and critical thinking about their learning processes. This can be achieved by providing additional guidance for learners engaged in Metacognitive Discourse Forums by scaffolding support and encouraging self-regulation and metacognitive reflection.

Educators should regularly monitor student progress, offer timely feedback, and adjust teaching strategies based on feedback gained from Metacognitive Discourse Forums. This approach allows for real-time adjustments to improve learning outcomes. Above all, educators should implement a combination of formative and summative assessments that are validated through rubrics and closely aligned with learning objectives. Use feedback from Metacognitive Discourse Forums to ensure assessments are fair and effective. By incorporating the Metacognitive Discourse Forums to facilitate reflective learning and problem-solving, instructors can improve the learning experience by ensuring user-friendly interfaces, such as using Dropbox, providing clear instructions, and making technical support readily available.

By implementing these recommendations, educators can ensure flexible teaching and learning using Metacognitive Discourse Forums, especially in STEM education. Educators should continuously evaluate and refine their action plans based on feedback and evolving needs, ensuring a sustainable and impactful approach to teaching and learning.

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Professional Development Workshops for Faculty on Addressing Implicit Bias in Computer Science Education

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Abstract: The "Understanding Implicit Bias" workshops were offered to Science, Technology, Engineering, and Mathematics (STEM) faculty at an urban minority-serving undergraduate institution with a focus on addressing the gender gap in computer science. The workshops aimed to raise awareness of implicit (unconscious) biases and provide practical strategies for addressing them, fostering a more inclusive classroom environment. Analysis of pre- and post-survey responses indicated an increase in participants' awareness of implicit biases in their discipline and a greater openness to taking steps to address them, suggesting the workshops' potential impact on promoting inclusive teaching practices.

Keywords: professional development, implicit bias, computer science, undergraduate education

INTRODUCTION

The under-representation of women in computer science continues to be a persistent national challenge. Despite ongoing efforts to close the gender gap in STEM fields, the proportion of computer science bachelor's degrees awarded to women remains around 20%. From 2015 to 2020, the New York City College of Technology (City Tech) MSEIP (Minority Science Engineering Improvement Program), funded by the U.S. Department of Education, implemented various strategies to increase the participation of women and minorities in computer science. One particularly successful strategy was a faculty professional development workshop on "Understanding Implicit Bias," which aimed to facilitate a shift in the gender equity dialogue. Using materials like "Breaking the

Bias Habit[1]" developed by WISELI: University of Wisconsin-Madison Inclusion in Science & Engineering Leadership Institute, participants explored implicit bias, its effects on classroom dynamics, and developed actionable plans to create a more inclusive and supportive environment for all students.

This article examines the outcomes of faculty workshops designed to raise awareness of implicit bias[2] in STEM education. Through an analysis of pre- and post-survey responses from participants, the study explores shifts in their understanding of implicit bias and its potential impact on teaching practices. The aim is to assess how these workshops may influence faculty perceptions and actions towards fostering more inclusive and equitable learning environments in STEM classrooms. Additionally, the article seeks to provide a model for future professional development initiatives aimed at enhancing teaching and learning in STEM disciplines.

LITERATURE REVIEW

Studies have shown that hidden bias across workplaces remains pervasive (Newman et al., 2025), with real effects on recruitment and retention impacting areas such as income, hiring decisions, and career advancement opportunities (McCormick, UNC Executive Development, 2016; Oberai & Anand, 2018). Implicit bias training has been widely promoted as a strategy to help individuals recognize and mitigate these biases, fostering more equitable and inclusive environments. Such training is particularly critical in fields like healthcare, where biases not only perpetuate systemic inequities but also directly impact the quality of care and services provided to diverse populations (Marcelin et al., 2019; Carnes et al. 2023).

However, research has raised important questions about the effectiveness of implicit bias training. A review by Moller et al. revealed that many unconscious bias interventions fail to produce lasting behavioral changes or significant shifts in Implicit Association Test (IAT) scores (Moller, et al. 2023). This suggests that while these interventions may raise awareness, they often fall short of achieving meaningful, long-term outcomes. An article in *Harvard Business Review* titled "Unconscious Bias Training That Works" stresses the importance of embedding practical strategies into such training programs. Without actionable steps, training programs are often ineffective (Gino & Coffman, 2021).

Additionally, studies such as the one by Pritlove et al. caution against an over-reliance on implicit bias training as a standalone solution. They highlight the danger of focusing solely on individual biases, which can obscure the broader systemic, structural, and political barriers that sustain

[1] WISELI no longer offers this workshop. For information, contact wiseli@engr.wisc.edu.

[2] In this article, we use the following terms interchangeably: hidden bias, implicit bias, and unconscious bias.

inequities (Pritlove, et al. 2019). While implicit bias training may help shift individual attitudes and behaviors, it is essential to recognize its limitations and the complexity of the issues at hand. Addressing these challenges requires a dual approach that combines individual-level efforts with systemic reforms. Without this balance, there is a risk of oversimplifying the problem and placing undue responsibility on individuals rather than institutions, which ultimately hold the power to enact lasting structural change.

Understanding Implicit Bias and Its Role in Education

Implicit biases, or unconscious perceptions, can create (intended or unintended) barriers for certain groups in their academic advancement (Harrison-Bernard et al., 2020; Beasley & Fischer, 2012). Rooted in stereotypes, prejudices, or discriminatory views, these biases shape generalized expectations that hinder equitable outcomes (Llorens et al., 2021). For instance, Copur-Gencturk et al. examined how teachers' implicit biases about the mathematical abilities of girls and students of color can negatively affect their confidence and performance in STEM disciplines (Copur-Gencturk, 2023).

Given the profound influence of faculty attitudes and actions on students' academic and social experiences, training to address implicit biases is essential (Harrison-Bernard et al., 2020; Rodriguez et al., 2021). Cultural change within academic institutions demands a multi-level approach, starting with faculty engagement (Carnes et al., 2021). Creating a fair and inclusive environment requires intentional actions to dismantle inequities perpetuated by biases and stereotypes. Without addressing these ingrained ideologies, meaningful cultural shifts will remain unattainable (Carnes et al., 2021; Llorens et al., 2021).

Professional development workshops have emerged as pivotal in promoting high impact practices in education. These workshops aim to raise faculty awareness of implicit biases and their impacts, fostering reflective self-perception. The concept of "bias literacy," introduced by the American Association for the Advancement of Science (AAAS), offers a framework for identifying and mitigating the effects of implicit bias. Through bias literacy, educators can better understand how preconceived notion or stereotypes influence their decision-making, behavior, and interactions with students, often resulting in inequitable treatment in academic settings (Carnes et al. 2012).

Educators increasingly adopt asset-based pedagogy and culturally responsive teaching to complement their understanding of implicit bias, building on their awareness of unconscious stereotypes and their potential impact on teaching practices. Recognizing implicit bias is a crucial first step in fostering inclusivity, but it must be paired with actionable strategies to create meaningful change. Asset-based pedagogy provides a pathway for addressing bias by emphasizing the strengths, cultural backgrounds, and life experiences that students bring to the classroom, rather than focusing on perceived deficits. This approach affirms the diverse knowledge and skills of students, fostering a more inclusive and engaging learning environment (Graham et al. 2013).

Culturally responsive teaching extends this effort by tailoring curricula and instructional strategies to reflect and resonate with the diverse backgrounds of students. It prioritizes creating inclusive learning experiences that address the needs of underrepresented and marginalized groups, fostering a sense of belonging and connection. Together, these methodologies not only help educators counteract the effects of implicit bias but also represent a broader shift toward equitable practices in computer science education. By embracing these approaches, educators can enrich the learning environment, enhance student engagement, and promote greater participation and success in STEM fields among diverse populations (Graham et al., 2013).

METHODOLOGY

Workshop Design

From 2016 to 2019, a series of professional development workshops for faculty were designed and conducted to promote inclusive teaching practices. These workshops combined implicit bias training with professional development in pedagogy, aimed to foster inclusive teaching and learning within the computer science disciplines. They specifically targeted faculty in computing-related fields, including mathematics, computer science, computer systems, computer engineering, and other STEM areas.

Faculty participation in the workshops was encouraged through an open call and department chairs' recommendations, allowing for both self-selection and broader outreach. Separate sessions were created to address the specific needs and contexts of part-time and full-time faculty, ensuring the content was relevant and impactful for each group.

- **Part-time Faculty:** The workshops focused on developing high-impact pedagogies for fostering an inclusive classroom environment. They were delivered over two consecutive days before the semester began to accommodate participants' schedules.

- **Full-Time Faculty:** The workshops addressed both classroom and pedagogical practices, extending beyond to examine departmental practices. Held at the beginning, mid-term, and end of the semester, these sessions encouraged reflection and sustained engagement, to foster long-term impact on departmental climate and culture.

Core Workshop Components

1. ***Understanding Implicit Bias — Changing the Gender Equity Equation*:** This session introduced the "Breaking the Bias Habit" workshop developed by WISELI. Participants examined implicit bias habits and crafted action plans to support a positive classroom climate. The session included an activity featuring the "Gender-Leader Implicit Association Test

(IAT)" by Project Implicit[3], which facilitated self-reflection on unconscious associations. This foundational component set the framework for subsequent pedagogical and discipline-specific discussions.

2. ***Best Practices in Pedagogy for an Inclusive Classroom*****:** This session centered on effective teaching strategies to engage and support women in computing. It emphasized high-impact practices to foster an inclusive and supportive classroom setting. Participants collaborated in small groups to share their experiences and brainstorm actionable approaches for creating supportive learning environments.

3. ***Problem-Solving and Computational Thinking*****:** With a focus on the "Computer Science for All" initiative, this session highlighted the importance of integrating computer science education across disciplines to broaden its accessibility and inclusivity. Participants were encouraged to develop strategies such as lesson plans, projects, or initiatives aimed at improving the learning environment. Discussions also addressed best practices for promoting accessible learning spaces, including crafting inclusive syllabi and interdisciplinary curricula.

Throughout the workshops, participants shared best practices within their disciplines, fostering a collaborative exchange of ideas to address biases in teaching and learning.

The workshop concluded with participants creating a strategy or action plan to cultivate change in their teaching practices. Deliverables included lesson plans, projects, or initiatives aimed at improving the classroom climate and promoting an inclusive classroom in STEM disciplines with a focus in supporting and transforming computer science education.

Participants were tasked with identifying one actionable change in their pedagogical practices as the deliverable. Part-time faculty presented their deliverables mid-semester. Full-time faculty shared their deliverables during the final workshop at semester's end.

To evaluate the workshops, participants completed anonymous pre- and post-surveys using unique codes to link responses while maintaining anonymity. These surveys measured changes in participants' awareness and perceptions related to implicit bias. For the data analysis, we used a two-tailed paired-sample t-test to determine whether there were statistically significant differences between the pre- and post-survey responses.

[3] Project Implicit, Implicit Association Test (IAT) https://implicit.harvard.edu/implicit/takeatest.html

Demographics of Workshop Participants

Full-Time Faculty Participants (2016–2017)

- Total Participants: 25 (12 in 2016, 13 in 2017)
- Affiliation: 84% from New York City College of Technology; 16% from Borough of Manhattan Community College
- Departments: Mathematics (44%), Computer Science/Systems (40%), Computer Engineering (12%), Chemistry (4%)
- Gender: 48% male, 52% female
- Ethnicity: 52% Asian/Pacific Islander, 40% White/Caucasian, 8% Other

Part-Time Faculty Participants (2017, 2019)

- Total Participants: 45 (23 in 2017, 22 in 2019)
- Affiliation: 93% from New York City College of Technology; 7% from Borough of Manhattan Community College
- Departments: Mathematics (38%), Computer Systems (49%), Computer Engineering (13%)
- Gender: 62% male, 38% female
- Ethnicity: 27% Asian/Pacific Islander, 33% White/Caucasian, 22% African American, 9% Hispanic/Latino, 2% Native American

RESULTS

A survey was administered both before and after the workshop series to the full-time faculty participants. Using unique codes to link responses, we were able to match 22 participants and measure changes between their pre- and post-survey responses. A copy of the full-time faculty survey is available in Appendix A.

Full-Time Faculty Survey Responses Part I: Gender Bias Awareness					
(1=Strongly Disagree and 7=Strongly Agree)	**Mean (Pre-Survey)**	**Standard Deviation (Pre-Survey)**	**Mean (Post-Survey)**	**Standard Deviation (Post-Survey)**	**Two-tailed paired sample t-test p value**
1. Decreasing automatic stereotypic associations is a valuable goal	5.91	1.74	6.82	0.50	0.027
2. Decreasing automatic stereotypic associations benefits society as a whole	5.95	1.79	6.77	0.43	0.053

3. To what extent do you think that you are vulnerable to unknowingly discriminating against women?	3.95	1.91	4.36	1.76	0.107
4. How aware are you to your own subtle expression of gender bias?	4.64	1.40	5.27	1.12	0.100
5. How aware are you to subtle forms of gender bias in the world around you?	5.29	1.68	5.95	1.05	0.022
6. There is no gender bias in my discipline.	3.59	2.36	3.32	2.01	0.367
7. There is no gender bias in my department.	4.77	2.16	4.41	2.15	0.401

Table 1: Full-time faculty survey results from 2016 and 2017. Part I: Gender Bias Awareness (22 matched pre- and post-survey responses).

Full-Time Faculty Survey Responses Part II: Self-Efficacy and Outcome Expectations					
(1=Strongly Disagree and 7=Strongly Agree)	**Mean (Pre-Survey)**	**Standard Deviation (Pre-Survey)**	**Mean (Post-Survey)**	**Standard Deviation (Post-Survey)**	**Two-tailed paired sample t-test p value**
1. Action: Recognize when gender bias is occurring during a work-related interaction (e.g., department meeting).					
• I am confident that I can do this.**	5.18	1.56	6.14	1.04	0.001
• I would benefit from doing this.	5.62	1.36	6.38	0.80	0.010
• It would be risky for me to do this.	3.71	1.62	3.81	1.78	0.785
• I engage in this action on a regular basis.	3.95	1.91	4.14	1.59	0.705
2. Action: Speak about gender equity in my workplace to my colleagues.					
• I am confident that I can do this.	5.14	1.82	5.45	1.68	0.452
• I would benefit from doing this.	5.77	1.19	5.57	1.08	0.407
• It would be risky for me to do this.	3.81	1.78	4.10	2.19	0.510
• I engage in this action on a regular basis.	3.62	1.88	4.14	1.82	0.134
3. Action: Replace a response based on gender stereotypes with a non-stereotypic response.					
• I am confident that I can do this.**	5.09	1.63	5.91	1.11	0.021
• I would benefit from doing this.	5.95	1.20	5.95	1.16	1.000
• It would be risky for me to do this.	3.00	2.00	3.14	1.88	0.826
• I engage in this action on a regular basis.	4.00	1.84	4.43	1.78	0.131

4. Action: Adopt the perspective (in the first person) of a woman who is being hired or evaluated for a leadership position.					
• I am confident that I can do this.	5.32	1.78	6.09	1.34	0.016
• I would benefit from doing this.	6.14	1.28	6.05	1.16	0.540
• It would be risky for me to do this.	2.29	2.03	2.86	1.77	0.192
• I engage in this action on a regular basis.	4.10	1.73	4.29	1.85	0.592
5. Action: Challenge a personnel decision if I think it has been influenced by gender stereotypes.					
• I am confident that I can do this.	4.19	2.20	5.23	1.63	0.014
• I would benefit from doing this.	5.77	1.54	5.52	1.08	0.397
• It would be risky for me to do this.	4.10	2.02	3.86	1.90	0.634
• I engage in this action on a regular basis.	3.14	2.15	3.57	1.89	0.406

Table 2: Full-time faculty survey results from 2016 and 2017. Part II: Self-Efficacy and Outcome Expectations (22 matched pre- and post-survey responses).

A survey was administered both before and after the workshop series to the part-time faculty participants. Using unique codes to link responses, we were able to match 34 participants and measure changes between their pre- and post-survey responses.

Part-time Faculty Survey Responses Gender Bias Awareness					
(1=Strongly Disagree and 7=Strongly Agree)	**Mean (Pre-Survey)**	**Standard Deviation (Pre-Survey)**	**Mean (Post-Survey)**	**Standard Deviation (Post-Survey)**	**Two-tailed paired sample t-test p value**
1. Decreasing automatic stereotypic associations is a valuable goal	5.91	1.75	6.44	0.93	0.136
2. Decreasing automatic stereotypic associations benefits society as a whole	6.06	1.56	6.38	1.02	0.303
3. To what extent do you think that you are vulnerable to unknowingly discriminating against women?	3.74	1.90	3.76	1.60	0.932
4. How aware are you to your own subtle expression of gender bias?	5.00	1.84	4.91	1.58	0.784
5. How aware are you to subtle forms of gender bias in the world around you?	5.24	1.50	5.53	1.33	0.278
6. There is no gender bias in my discipline.	3.91	2.21	3.97	2.22	0.783
7. There is no gender bias in my department.	4.27	2.04	4.38	1.95	0.659

Table 3: Part-time faculty survey results from 2017 and 2019. Gender Bias Awareness: 34 matched pre- and post-survey responses.

DISCUSSION

Comparing the pre- and post-survey responses for full-time faculty, we observed significant differences in several key areas related to recognizing and addressing implicit bias. Notable changes were identified in faculty perceptions on the following survey items, where the p-values from the two-tailed paired-sample t-tests were less than 0.05 ($p < 0.05$), indicating statistically significant differences:

- Decreasing automatic stereotypic associations is a valuable goal.
- How aware are you to subtle forms of gender bias in the world around you?
- Action: Recognize when gender bias is occurring during a work-related interaction (e.g., department meeting). (I am confident that I can do this.)
- Action: Replace a response based on gender stereotypes with a non-stereotypic response. (I am confident that I can do this.)
- Action: Adopt the perspective (in the first person) of a woman who is being hired or evaluated for a leadership position. (I am confident that I can do this.)
- Action: Challenge a personnel decision if I think it has been influenced by gender stereotypes. (I am confident that I can do this.)

In contrast, the part-time faculty showed no significant difference in their pre- and post-survey responses overall (large p-values $p>0.1$). However, when we disaggregated the 2019 part-time responses by gender and explored the trends among the pre- and post-responses of 8 female and 8 male part-time participants, some noticeable patterns emerged. After the conclusion of the workshop, female part-time faculty generally rated their awareness of bias lower on most post-survey questions compared to the initial responses. In contrast, male part-time faculty rated their awareness of bias higher on the post-survey compared to the pre-survey (see Table 4). This shift in responses suggests that gender may influence how faculty self-assess their awareness of bias and perhaps how they engage with the topic of implicit bias, which could be an area for further exploration. Specifically, the questions where these differences were observed included:

- To what extent do you think that you are vulnerable to unknowingly discriminating against women?
- How aware are you to your own subtle expression of gender bias?
- How aware are you to subtle forms of gender bias in the world around you?
- There is no gender bias in my discipline.
- There is no gender bias in my department.

The gender-based differences in responses raises important questions about the extent to which the workshop may have resonated differently with male and female part-time faculty. Additionally, responses to the last two questions were lower among female faculty compared to their male counterparts. This disparity suggests the need for further research to explore why these differences exist and how gender may influence faculty perceptions and their willingness to recognize and confront implicit bias.

Part-time Faculty Survey Responses Women versus Men Trend						
(1=Strongly Disagree and 7=Strongly Agree)	Women (N=8)			Men (N=8)		
	Pre	Post	Difference	Pre	Post	Difference
1. Decreasing automatic stereotypic associations is a valuable goal	6.13	6.38	0.25↑	6	6.88	0.88↑
2. Decreasing automatic stereotypic associations benefits society as a whole	6.25	6.25	0.00	5.88	6.75	0.88↑
3. To what extent do you think that you are vulnerable to unknowingly discriminating against women?	3.13	2.88	-0.25↓	3	3.13	0.13↑
4. How aware are you to your own subtle expression of gender bias?	5.5	4.75	-0.75↓	4.5	5.13	0.63↑
5. How aware are you to subtle forms of gender bias in the world around you?	5.88	5.75	-0.13↓	4.75	5.75	1.0↑
6. There is no gender bias in my discipline.	3.29	3.25	-0.04↓	4.88	5.88	1.0↑
7. There is no gender bias in my department.	3.71	3.5	-0.21↓	5	5.63	0.63↑

Table 4: Part-time faculty survey results disaggregated by gender (8 sets of pre- and post-responses by women and 8 sets by male part-time faculty).

Beyond the survey data, anecdotal feedback from participants highlighted a variety of responses and actions resulting from the workshop. While many participants acknowledged the gender disparity in computing fields and expressed a desire to bridge this gap, conversations around addressing potential biases often sparked defensiveness. Some faculty members initially rejected the notion that they might harbor biases, insisting that they treat all students equally. This response reflects how deeply ingrained biases can be, and how difficult it is to engage in these discussions without resistance. At times, the conversation shifted to concerns about "reverse discrimination" against men, particularly when discussing strategies to mitigate gender bias.

In one case, a male faculty member proposed randomized group assignments as an action plan to eliminate bias. However, this strategy contradicts research. Study suggests that in male-dominated STEM classrooms, intentionally grouping women together, where they represent the majority or are equally represented in group dynamics, is beneficial and can help create a positive "microenvironment" that empowers them (Dasgupta et al., 2015).

Despite these challenges and reservations, several meaningful changes emerged following the workshop. A male faculty member in the computer engineering department took the initiative to display posters featuring women in computing. This simple yet impactful gesture served as a reminder of the contributions of women to the field, offering visible role models and promoting a more inclusive environment within the department. Inspired by the workshop's emphasis on mentorship, a female part-time faculty member sought out mentorship for herself and also began mentoring female students. A part-time faculty member extended the impact beyond CUNY by researching women's enrollment and graduation data at another institution where she held a full-time position.

Notably, a male faculty member who had initially expressed concerns about these conversations being a form of "reverse discrimination" later became a strong advocate for supporting women in computing. Additionally, many faculty members introduced assignments and projects that encouraged students to explore personal interests and engage in creative expression. These efforts fostered more inclusive, student-centered, and asset-based learning environments in computing classes.

Overall, the workshop has had a tangible impact on participants, though varying levels of understanding and resistance highlight the complexity of addressing implicit bias in academia. While some faculty members embraced the ideas and strategies presented, others struggled with the concept of implicit bias and the potential for bias in their own actions. Further work is needed to ensure that all faculty members engage with these issues in a meaningful way, and that sustainable changes to classroom environments and teaching practices are made.

CONCLUSIONS

The under-representation of women in computing fields remains a persistent and significant challenge, one that demands targeted and thoughtful interventions at all levels of education. The faculty professional development workshop, "Understanding Implicit Bias to Change the Gender Equity Equation," was a crucial step in initiating a culture shift within computer science education. This workshop not only served as a professional development opportunity but also as a call to action for faculty to reflect deeply on their own teaching practices, departmental dynamics, and the broader institutional culture. By engaging faculty in discussions about implicit bias and gender equity, the workshop encouraged participants to take tangible steps toward fostering more inclusive classrooms and departments that support the success of all students, particularly women and other underrepresented groups.

While the workshop demonstrated the potential impact of faculty professional development in creating a more equitable learning environment, it also revealed the complexities of addressing long-held beliefs and behaviors. Many faculty members embraced the insights provided, yet the discussions surrounding bias and its effects on teaching and decision-making highlighted the ongoing nature of this work. The resistance and defensiveness that some participants initially expressed, particularly in relation to their own biases, underscored the challenge of confronting such sensitive issues. Nonetheless, the workshop prompted meaningful reflection and action, with several faculty taking proactive steps to implement changes in their teaching approaches and classroom environments. However, it is clear that continuous effort and sustained engagement will be necessary to achieve lasting change in addressing gender disparities in computing. Beyond individual efforts, institutional dialogues are crucial for driving policy and systemic changes. These dialogues are essential for developing and implementing policies that reinforce a commitment to supportive and accessible learning spaces across the institution. Creating an environment where all students feel seen and heard and empowered requires not only individual reflection but also coordinated institutional action. The insights gained from this workshop can serve as a foundation for both faculty-driven and institutional-wide initiatives, acting as a catalyst for broader systemic change. By deepening faculty awareness and fostering ongoing institutional conversations, such initiatives can help drive lasting transformation that supports the advancement of women and other underrepresented groups in STEM fields.

IN MEMORIAM

We dedicate this paper to our cherished colleague, team member, and friend, Dr. Janet Liou-Mark, who passed away in September 2020. Her unwavering kindness, empathy, and dedication to supporting students and colleagues left a lasting impact on all who had the privilege of working with her. Her spirit continues to inspire us.

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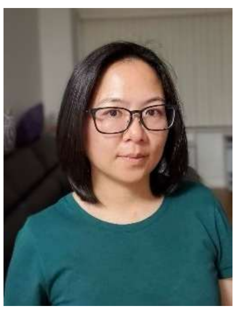

Suhua Zeng is a lecturer at the New York City College of Technology, where she teaches various levels of math courses. She focuses on exploring diverse teaching methods to enhance student engagement and comprehension of complex concepts, contributing to more impactful learning outcomes. She also specializes in helping students seeking advice for planning and registering for their mathematics courses.

APPENDIX A (The survey was provided by WISELI https://wiseli.wisc.edu and adapted for New York City College of Technology MSEIP project.)

NEW YORK CITY COLLEGE OF TECHNOLOGY

Who? Me? Understanding Implicit Bias: A Workshop for Changing the Gender Equity Equation

Post-Survey

SECTION 1: CONSENT STATEMENT

You are being asked to participate in a Department of Education Minority Science and Engineering Improvement Program funded study titled "Curricular and Strategic Changes in Mathematics to Increase and Sustain the Participation of Women and Underrepresented Minority Students in Computer Science and Enhance Institutional STEM Education" to promote Bias Literacy, a term used by the American Association for the Advancement of Science (AAAS), as a way to enhance the institutional climate for students majoring in computing. This study examines opinions, beliefs, and equity self-efficacy. Should you choose to participate, it will take you approximately 15 minutes to complete this survey. To facilitate longitudinal analysis, your results will be linked to your future/past administrations of this survey via a unique identifier that you create. Because the researchers will have no way to link the identifier to you, your responses are anonymous, thus reducing or eliminating the risk of a breach of confidentiality.

Your participation in this survey is voluntary and you can withdraw from participation at any time by not answering the questions. If you have questions about this survey or how the data will be used, please contact the study director: [redacted] *If you have any questions about your rights as a research subject, please contact* [redacted] *Human Research Protection Program (HRPP) Coordinator at* [redacted]

SECTION 2: ACROSTIC

Because you will be asked to complete this survey multiple time, we need to be able to match your responses across time in a way that does not identify you. To create your identifier please complete the following:

__ __ Mother's (or mother figure's) maiden name (first 2 letters only)
__ __ Father's (or father figure's) first name (first 2 letters only)
__ __ Last two digits of your cell phone number

SECTION 3: GENDER AND LEADERSHIP IMPLICIT-ASSOCIATION TEST (IAT)

Please go to the following American Association of University Women's website and take the 10 minute IAT using the following link: http://www.aauw.org/article/implicit-association-test/

Record your results here by circling one response:

Your data suggest [no association/slight association/moderate association/strong association] of [Male/Female] with Leader and [Female/Male] with Supporter, compared to [Female/Male] with Leader and [Male/Female] with Supporter.

SECTION 4: GENDER BIAS AWARENESS (PART I)

Statement	Circle one						
Decreasing automatic stereotypic associations is a valuable goal	1 Strongly disagree	2	3	4 Neither	5	6	7 Strongly agree
Decreasing automatic stereotypic associations benefits society as a whole	1 Strongly disagree	2	3	4 Neither	5	6	7 Strongly agree
To what extent are you personally concerned about your performance on the IAT?	1 Not at all concerned	2	3	4 Neither	5	6	7 Very concerned
To what extent do you think that you are vulnerable to unknowingly discriminating against women?	1 Not at all vulnerable	2	3	4 Neither	5	6	7 Very vulnerable
How aware are you to your own subtle expression of gender bias?	1 Not at all sensitive	2	3	4 Neither	5	6	7 Very sensitive
How aware are you to subtle forms of gender bias in the world around you?	1 Not at all sensitive	2	3	4 Neither	5	6	7 Very sensitive

Supported by a Department of Education MSEIP grant # P120A150063
Survey provided by the WISELI at the University of Wisconsin Madison

SECTION 5: SELF-EFFICACY AND OUTCOME EXPECTATIONS

Statement	Circle one						
Action: Recognize when gender bias is occurring during a work-related interaction (e.g., department meeting).	Strongly disagree			Neither			Strongly agree
I am confident that I can do this.	1	2	3	4	5	6	7
I would benefit from doing this.	1	2	3	4	5	6	7
It would be risky for me to do this.	1	2	3	4	5	6	7
I engage in this action on a regular basis.	1	2	3	4	5	6	7
Action: Speak about gender equity in my workplace to my colleagues.							
I am confident that I can do this.	1	2	3	4	5	6	7
I would benefit from doing this.	1	2	3	4	5	6	7
It would be risky for me to do this.	1	2	3	4	5	6	7
I engage in this action on a regular basis.	1	2	3	4	5	6	7
Action: Replace a response based on gender stereotypes with a non-stereotypic response.							
I am confident that I can do this.	1	2	3	4	5	6	7
I would benefit from doing this.	1	2	3	4	5	6	7
It would be risky for me to do this.	1	2	3	4	5	6	7
I engage in this action on a regular basis.	1	2	3	4	5	6	7
Action: Adopt the perspective (in the first person) of a woman who is being hired or evaluated for a leadership position.							
I am confident that I can do this.	1	2	3	4	5	6	7
I would benefit from doing this.	1	2	3	4	5	6	7
It would be risky for me to do this.	1	2	3	4	5	6	7
I engage in this action on a regular basis.	1	2	3	4	5	6	7
Action: Challenge a personnel decision if I think it has been influenced by gender stereotypes.							
I am confident that I can do this.	1	2	3	4	5	6	7
I would benefit from doing this.	1	2	3	4	5	6	7
It would be risky for me to do this.	1	2	3	4	5	6	7
I engage in this action on a regular basis.	1	2	3	4	5	6	7

SECTION 6: GENDER BIAS AWARENESS (PART II)

Statement	Strongly disagree			Neither			Strongly agree
There is no gender bias in my discipline.	1	2	3	4	5	6	7
There is no gender bias in my department.	1	2	3	4	5	6	7

SECTION 7: DEMOGRAPHICS

College: ______________________ Department: ________________ Gender: □ Male □ Female

Ethnic Background (Check all that apply): □ African American □ Hispanic/Latino □ Asian/Pacific Islander □ Caucasian □ Native American □ Other

Tenure Status: □ Yes □ No Professorial Rank: □ Assistant Professor □ Associate Professor □ Professor

Number of Years Teaching: ____ Number of Years Teaching at Your Current Institution: ____

Designing Equity-Focused Pedagogy in Mathematics Teacher Preparation with Digital Data Tools

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Abstract: This study examines the implementation of a course module that integrated computing and data analysis. The module aimed to engage prospective mathematics teachers in the practice of working with datasets and analyzing data to investigate questions related to local Brooklyn schools, as well as to gain deeper insight into the students and communities where they conduct their field experiences. Throughout the module, teacher candidates explored issues such as student learning opportunities, achievement gaps, school segregation, educational (in)equity, and other social justice concerns through readings, data analysis, and direct engagement. They shared and reflected on their findings with peers, deepening their understanding of these topics through collective discussion. The teacher candidates expressed mixed perceptions about the potential of incorporating computing and data analysis into mathematics teaching and learning. While many acknowledged that such integration could enhance instruction by connecting mathematical concepts to real-world issues—such as poverty rates and rising global temperatures—and by helping students make sense of the world, relate mathematics to their own lives, and engage with social justice issues, there was also a shared concern. Most believed that implementing this approach would require substantial additional planning and would likely not be feasible during the early years of their teaching careers.

Keywords: mathematics teacher education, computational thinking, data analysis, critical dialogue, equitable teaching, culturally responsive pedagogy

INTRODUCTION

The authors are interested in enriching mathematics teacher education by including computational thinking and digital literacies (CDL) in teacher education and including more versatile and contemporary approaches to mathematical modeling, as well as incorporating critical perspec-

tives on computational thinking and mathematical modeling at its intersections with social issues.
We believe that computational thinking, digital literacies, and modeling can help prospective mathematics teachers engage their students with more authentic mathematics problem solving and modeling with more efficient and powerful technology tools. We are also persuaded of the importance of incorporating critical perspectives on computational and mathematical thinking and modeling as such perspective is essential in teaching that is equitable and culturally responsive and for participating in a democratic society.

In the summer of 2022, we joined the CUNY Computing Integrated Teacher Education (CITE)) -- a multi-year initiative to support CUNY faculty in integrating state standards and aligning computing content and pedagogy with required education courses, field work, and student teaching. The initiative focuses on supporting institutional change in teacher education programs; supporting faculty computing pedagogical content knowledge through the lens of culturally response-sustaining education; and faculty research in equitable computing education and STEM pedagogies. Its core value is equity, and "equitable pedagogies, which seek to empower learners and communities, promote meaningful and joyful learning, and transform institutions towards justice" (The CUNY CITE Equity Working Group, 2023). All CITE work is guided by the following design principles: "co-learning and co-construction of knowledge in communities; supporting learner agency in experimenting with, modifying and creating tools; encouraging creativity and expression; mobilizing computing for social action; vetting and critiquing tools and tech cultures; and adopting expansive notions of learning" (The CUNY CITE Equity Working Group, 2023).

Prior to the CITE initiative, our team had already embarked on computing integration by designing and piloting computational modeling projects with prospective mathematics teachers. Joining CITE helped us layer on computing and digital literacies (CDL) and get support from a diverse group of colleagues. Initially, we were focused exclusively on introducing teacher candidates to programming and coding. We consider that an expanded conception of computing integration would be much more valuable to prospective teachers, not only in terms of enhancing their mathematics teaching, but also in preparing them to use various technology tools critically. CITE offered us experimental space in which our team could learn, create, discuss, and try out our ideas and artifacts. The CITE initiative helped us reconceptualize computing integration as a larger domain, encompassing not only coding and computational modeling, but digital literacy, and the use of digital tools, accompanied by a critical stance on technology, mathematics, and their uses.

As part of our work related to CITE, we developed a course module to support prospective mathematics teachers in developing data analysis and critical thinking skills. The module was designed to engage teacher candidates in analyzing and visualizing data from education data sets, posing questions, analyzing and interpreting data to answer the questions, and visualizing interpretations to communicate findings. The module also engaged teacher candidates in exploring school segregation, educational opportunities, and education (in)equities in the context of these data analyses and visualizations. In addition, we planned for discussion among teacher candidates of bias in databases and data representations, of how bias can be introduced or guarded against, and the impact of data technologies on society and individuals. The course module was informed by the *New York State K12 Computer Science and Digital Fluency Learning Standards* (2024), the *NYS Culturally Responsive-Sustaining Education Framework* (2024), and the *Equitable CITE Pedagogy and Design Principles Framework* (CUNY CITE Equity Working Group, 2023). The module was featured on the CUNY CITE website (Kennedy, 2023).

The purpose of our research project was two-fold. It aimed at: a) exploring the implementation of a module with integrated computing components designed for preservice mathematics teachers, and b) exploring their perceptions of the mathematics teacher candidates of the potential of computing integration in mathematics teaching and learning.

The research questions which guided the study were as follows:

RQ1: What are the characteristics of the implementation process of the course module with integrated computing component designed for mathematics preservice teachers? What kind of teacher learning did it facilitate, if any?

RQ2: How do preservice teachers perceive the potential of integrating computing, and data analysis in particular, in mathematics teaching and learning? What are their beliefs about the challenges and opportunities of such integration?

LITERATURE REVIEW

The emergence in recent years of multiple integrated fields such as computational biology, computational chemistry, computational geometry, and computational physics is a testimony to the power of computation and the potential of its integration with classical STEM fields in order to solve more complex problems. The notion of CDL integration into STEM classrooms is relatively new. Computational thinking (CT) is understood as the thought process involved in formulating problems whose solutions can be expressed as computational steps or algorithms to be carried out by a computer (Lee et al., 2019). CDL is a more expansive notion, which in addition to CT also includes computing and digital literacies such as tinkering, experimenting, digitally supported communication, critically and ethically navigating digital tools and more (Vogel, Patel, Yadav, 2025). Many researchers argue for the inclusion of CDL in mathematics and science classrooms (e.g., Weintrop et al., 2016; Lee et al., 2019). Some see such integration as creating the potential for students to build a strong and mutually supportive relationship between mathematical knowledge and computational knowledge (Weintrop et al., 2016). It has been suggested that students who learn to engage with and use computational methods and tools will advance their understanding of mathematics and will gain awareness of current applications of CT in mathematics and across STEM fields. Others insist that the integration of mathematics and CT allows students to engage with real-world problems, authentic tools, and authentic mathematics practices (Bain et al., 2021). There has in fact been progress in elucidating what the integration of CT and mathematics looks like in the classroom (e.g., Kennedy, Kostadinov, Masuda, 2024; Benakli et al., 2016; Bain et al., 2021) but work on the integration of CT in the mathematics classroom is still needed, ranging from project designs to pedagogies. While some mathematical problems lend themselves to computational approaches, problems and course modules often need to be reframed so that existing computational tools can be utilized.

The integration of computational thinking and computer science in K-12 education has been an ongoing process for decades (Nouri et al., 2020; Wing, 2006; 2008). For CDL to become part of the K-12 curriculum, it is imperative that teachers are well trained to incorporate CDL in their teaching (Barr & Stephenson, 2011). Teacher education plays a critical role in equipping pre-service teachers with the knowledge and skills needed to teach CDL and integrate it into their practice (Yadav, Stephenson, & Hong, 2017). Before implementing CDL in teacher preparation programs, it is important to gain a better understanding of both the process of computing implementation, and the prospective teachers' perceptions of CDL integration. This study attempts to shed light on both of these issues.

METHODS

Design

We adopted an exploratory case study approach (Yin, 2017), centered around examining the implementation of the designed course module with a group of eight mathematics teacher candidates and the learning it engaged teacher candidates in. For this research study, we combine four data collection instruments (authors' descriptive and reflective notes, participants' work relevant to the study and transcripts from class discussions, and participants' focus-group interview).

Study Context and Participants

The participants in the study are eight prospective mathematics teachers taking a mathematics education course in Fall 2022, which was taught by the first author. The course participants are undergraduate prospective teachers in their second or third year of the undergraduate degree, who have completed an initial round of school observations of mathematics teaching and learning. At the completion of the program, they expect to obtain initial certificates and teach mathematics in grades 7 to 12 as full-time mathematics teachers in public NYC schools. The group of teacher candidates is invariably diverse in terms of race, ethnicity, education experiences, and age. A large percentage of these students have completed their middle and high school education outside of the United States.

The course module was designed for the aforementioned mathematics education course, which is part of the required undergraduate mathematics education program curriculum on campus. The course has a practice-oriented component, which includes 60 hours of intermediate field school-based experience, as well as lesson and unit planning, design of student assessment, and delivery of instruction. It involves micro-teaching – teaching small segments of lessons in real classrooms – which provides an appropriate context for prospective teachers to do some exploratory work with school data sets and to perform data analysis in order to learn more about the schools and students they will work with.

As part of the course work the prospective mathematics teachers are engaged in a course module "*Behind the Data: Analysis and Visualization of School and Student Data*." This computing integration module focuses on engaging prospective mathematics teachers in using data sets to answer questions about local Brooklyn schools and learn more about the schools and students where they do field experience. The purpose of the module is to support prospective teachers in developing data analytical and critical thinking skills. For the purposes of this module, we used multiple databases and other data resources, including the NYC open database https://opendata.cityofnewyork.us/, the Office for Civil Rights' Data on Equal Access to Education, and ProPublica's Miseducation database (ProPublica.org).

The original module is comprised of four activities, all of which are based on explorations of data sets. As part of these three activities, prospective teachers compare and contrast schools and educational services in different parts of NYC. They generate a profile of the school where they do field experience by analyzing and visualizing data from an education data set. Teacher candidates articulate a question about their school's student population and find, analyze, and interpret data to answer the question, and visualize interpretations to communicate findings. They explore data about schools and students, as well as relationships between variables (i.e., test scores, demographics, grades, school funding, inequity, and achievements). They are also tasked to investigate the relationship between segregation, educational opportunities, and (in)equities. Each activity ends with a discussion focused on questions related to segregation and (in)equity in education. The fourth activity was structured as a workshop on using R for data analysis with NYC Open database. It ended with a discussion about bias in databases and data representations, how bias can be introduced or guarded against, and the impact of data technologies on society and individuals. In the second iteration of the module design, we replaced the data analysis using of R —which required more extensive learning—with an activity built in CODAP, a more accessible data analysis platform.

Data Collection

The researchers took descriptive and reflective notes during the implementation of the course module. Teacher candidates' artifacts developed in relation to the course module were collected as well. All participants were invited to take part in a focus group interview, which took 60 minutes. The focus group interview started with an invitation to talk freely about their experience with the computational module. The interview was semi-structured, which allowed for follow up questions. The interview was recorded and transcribed for analysis. Consent forms were secured from all participants. All names of the participants were changed to ensure confidentiality.

RESULTS

Our course module integrated computing into an existing mathematics education course. Teacher candidates have read about the "achievement gap" and pervasive inequalities in learning opportunities in readings for previous mathematics education courses. This module, we thought, would offer them the occasion not only to learn more about their placement schools and their students, but also the chance to encounter head-on the drastic difference in the learning opportunities that NYC schools do (or don't) provide and reflect on them.

Our Intentions

Ultimately, we wanted to encourage prospective teachers to learn more about and to raise questions about their field-work schools and students and to draw conclusions about the educational opportunities available to students. The course module was also intended to challenge prospective teachers' beliefs and conceptions about education and schools. We grounded our work in themes that included (in)equity, school segregation, (in)equitable school funding, and availability of educational opportunities. The team wanted the prospective teachers to understand the deeper social issues that affect schools, education, and learning outcomes. We thought that it would be helpful for teacher candidates to leverage both qualitative methods – conducting observations and reading articles about NYC schools – and quantitative methods – analyzing numerical data about Brooklyn schools' funding, demographics, and other academic characteristics. On the quantitative side, we wanted to support prospective mathematics teachers in developing data analysis and critical thinking skills. For the purposes of this artifact, the team used various open data sets and data resources (see Appendix). The team also wanted to expose prospective mathematics teachers to "R" -- an integrated suite of software for data manipulation, calculation, and graphical display-- so that prospective mathematics teachers would experience "the power of R," and be motivated to learn more about using R in the future. We hoped that prospective teachers would experience how data analysis and data literacy could put their concrete experience into perspective and that it would help them understand it in the context of large social and educational phenomena. Towards those ends, we conducted discussions in line with a pedagogical model called "community of inquiry," which is a model for collective, democratic, and collaborative deliberation. We hoped that this approach would foster participant agency.

The Course Module

The course module is designed to engage prospective mathematics teachers in critical inquiry using real-world educational data sets. Centered around the Brooklyn schools where teacher candidates are placed for their micro-teaching field experience, it includes opportunities for prospective mathematics teachers to read articles, explore data sets, wonder, pose and answer questions, and engage in critical collective discussions. The module is implemented over four consecutive synchronous sessions held over Zoom. Assignments involve readings and a few homework tasks. During the first three 1.5-hour sessions, prospective mathematics teachers explore databases and engage in discussions guided by key questions. Prospective teachers investigate school demographics and educational opportunities (e.g., whether high-level math and statistics classes were available, the percentage of certified teachers, the available technology, etc.). Collective discussions are guided around data visualization, interpretation, and analysis, supporting students in making sense of the readings and of the contexts prospective teachers encountered in the schools and in drawing conclusions from the data. The final session, is designed as a 2.5-hour immersive workshop focused on the statistical package, R, introducing teacher candidates to basic data manipulation, filtering, and visualization techniques, allowing teacher candidates to extend their inquiry through coding.

Planned Activities at a Glance:

- ***Creation of school profiles through data analysis and visualizations:*** Teacher candidates explore education data sets, and analyze and visualize data related to their assigned field-work schools. They are guided to formulate questions about their schools' student populations and educational opportunities, and use data to analyze and interpret their findings. Each candidate is expected to developed a short presentation – including graphs and visualizations – about their school and its students and share with peers.
- ***Engagement and inquiry with data to understand educational inequity:*** Faculty and teacher candidates discussed the data that had already been collected about schools and students. Teacher candidates interpreted visualizations from various databases to compare and contrast schools and educational services in different parts of the country and in New York City in particular, where they explored relationships between variables (test scores, demographics, grades, etc.) related to social justice, (in)equity, and segregation.
- ***Critical discussions and reflections with data analysis:*** Each session ended with a discussion about critical educational issues such as quality education for all NYC students; available learning opportunities, school segregation, school funding, the impact of funding on student achievement, the broader consequences of segregated schooling for individuals and society, and potential strategies to address these inequities.
- ***Engagement with coding and data analysis with R:*** The final session introduced mathematics teacher candidates to R, guiding them in sorting and filtering data to answer specific questions, and visualize their findings.
- ***Discussions "for" and "against" particular uses of big data:*** Faculty facilitated conversations about the potential benefits of using educational data sets and data analysis in mathematics teaching and learning. Teacher candidates also examined the limitations of big data, interrogating assumptions that may have been made in data collection and visualization. Discussions highlighted what data sets often fail to capture—specifically, the nuanced details of communities and the individual characteristics of students.

In the course design iteration that followed the module's implementation in Fall 2022, the fourth activity, which originally involved data analysis using R, was replaced with an activity utilizing CODAP. This change was made to enhance accessibility and ease of use for students, particularly those with limited prior experience in programming. By integrating CODAP—a more intuitive, web-based data exploration tool—the course aimed to lower technical barriers while still achieving the intended learning objectives related to data analysis and interpretation. The new CODAP-based activity has been designed to engage teacher candidates in data exploration by mapping mathematics achievement scores of New York City schools, allowing comparisons across neighborhoods and against each neighborhood's Economic Index. The resulting graphs and maps reveal equity gaps that reflect broader economic disparities among ethnic demographics.

Course Module Implementation

The following section discusses the implementation of the first iteration of the designed course module, conducted in Fall 2022.

Creation of School Profile Through Data Analysis and Creating Visualizations

Prior to class sessions, prospective teachers were given an assignment to use the interactive map of the United States in and explore a few education data bases, including the Civil Rights Data Collection and Miseducation (ProPublica). They were instructed to review the "Opportunity," "Discipline," and "Achievement Gap" tabs, as well as the "Black" and "Hispanic," demographic tabs. Additionally, they were asked to search for their field experience school and district in the databases, make notes of what they noticed in the results and write down questions that arose from the data. Prospective teachers were asked to prepare a one-page report summarizing their discoveries about their schools and school districts. In their reflection, they were instructed to include detailed results, graphs and tables from the databases, and be ready to share their findings in class.

At the beginning of the session, the prospective teachers were invited to share their reports and findings, particularly noting anything they found unexpected and surprising. The guiding question was: What did you find about your school/school district? They were also invited to comment on how the database explorations helped make previously unseen patterns or disparities visible to them. The excerpts of candidates' findings, given below, show some very different school profiles. The names of the specific schools have been withheld or changed.

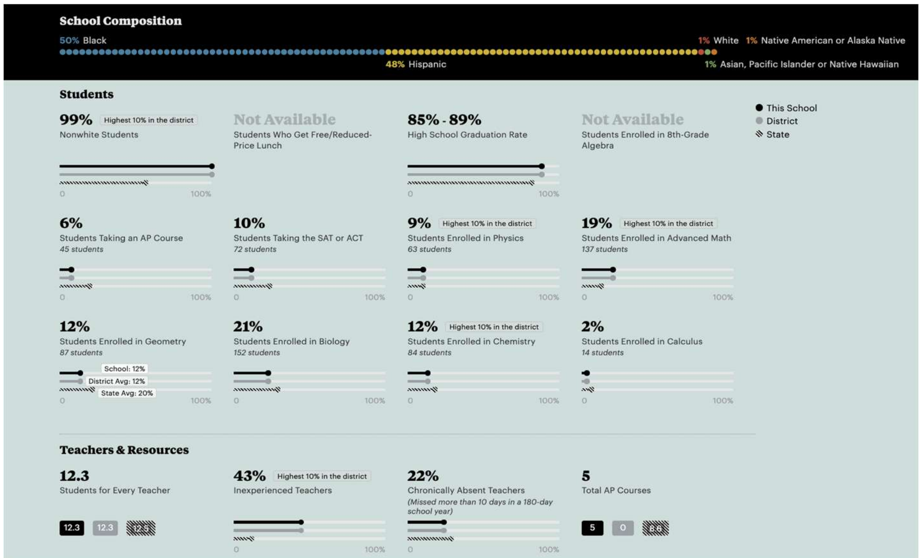


Figure 1: Excerpt from teacher candidate A’s profile of their NYC field placement school

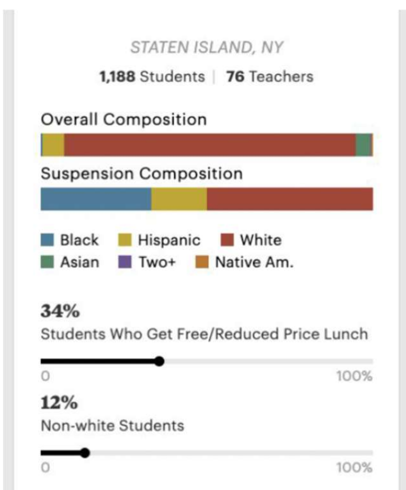
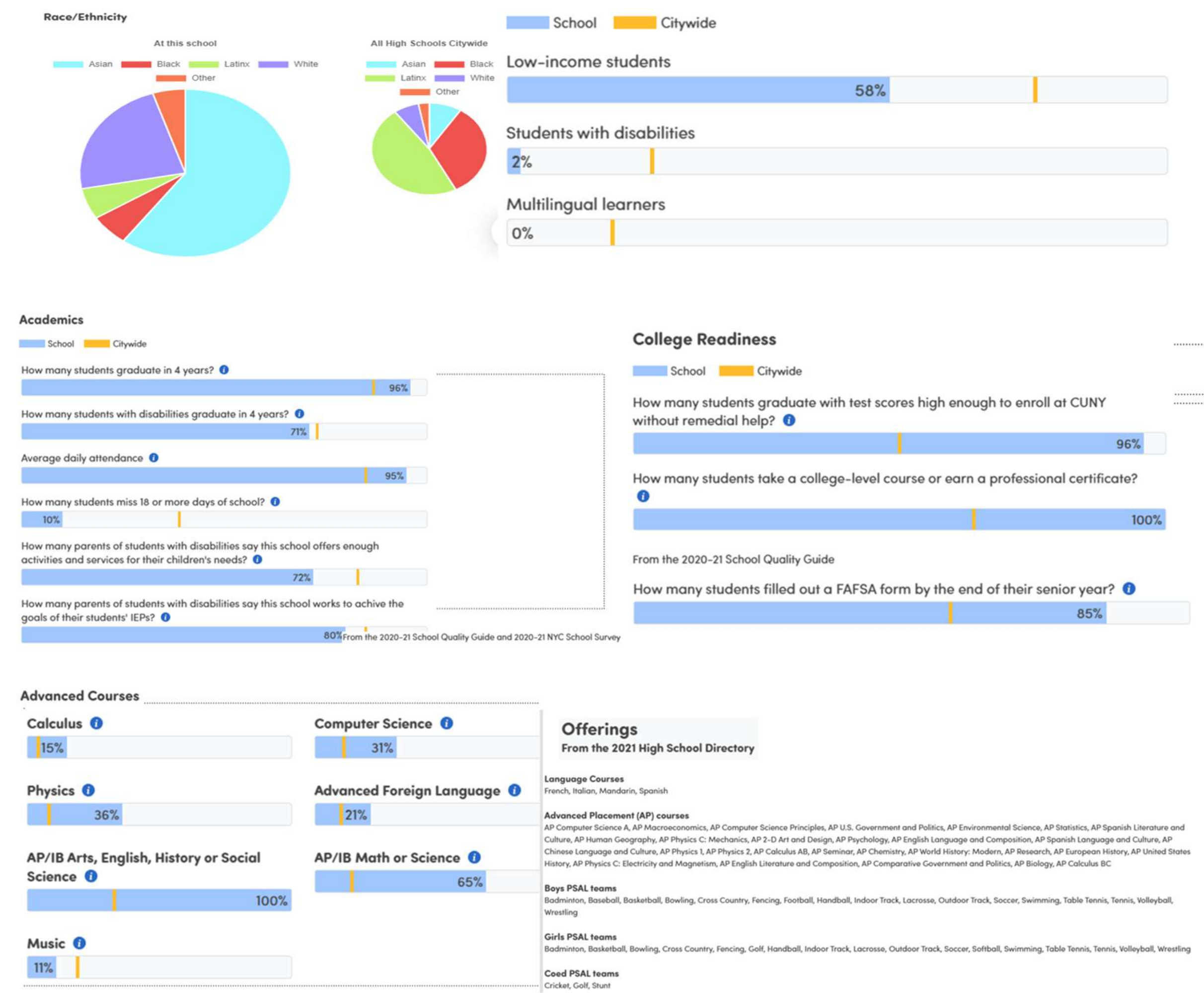


Figure 2: Excerpt from teacher candidate B’s profile of their NYC field placement school



“Based on the research on *Brooklyn Star high school*, students have more opportunities than NYC citywide students…. The students take more AP courses and have more options to choose from four foreign languages and 20 AP courses (vs. citywide average 4.9). Their achievement is in the highest 10% in the NYC DOE schools even though their student teacher ratio is twice higher than citywide. The student population of *Brooklyn Star high school* is mainly Asian (Chinese 60%) and White (23 %) much higher compared to the percentage of Asian and White student population in NYC, which are 9% and 7% respectively. There are no ELL students admitted in this school and the school has very few students with SPED. Most students (96%) graduate on time. Every student takes at least one college course.”

Note: The name of the school has been changed.

Figure 3: Excerpt from teacher candidate C's profile their NYC field placement school

Engagement and Inquiry with Data to Understand Educational Inequity

In the next phase of the module, the teacher candidates engaged in reading journal and newspaper articles, listening to an episode of The Daily and in_using the data sets to investigate relationships between inequity, segregation, school funding, and achievement. During the second session, the candidates' inquiries focused on identifying key variables to explore, supported by a modeled demonstration of how to navigate data sets and data analysis. Through these analyses, the candidates found that about 51% of the nation's school students are in "racially concentrated districts," where over 75 percent of students are either white or nonwhite. They also found that both NYC schools, as well as many of the schools where they were placed for field experience mirrored these patterns of racial concentration and segregation. Data overwhelmingly supported the conclusions drawn by the group: Black and Hispanic students are several times more likely to get suspended than White students. White students have significantly higher chances of being in advanced placement classes than Black or Hispanic students. Schools with higher percentages of Black and Hispanic students are likely to have lower graduation rates. The candidates wondered whether the "achievement gap" varied significantly between urban and rural contexts, and how these differences might have been exacerbated during and after the COVID-19 pandemic. One candidate shared insights gained from watching a PBS Frontline documentary (Growing Up Poor in America, FRONTLINE, noting that while New York State was able to provide students with laptops and tablets during remote learning, students in Alabama had to travel to their schools to use computers on-site or access wifi. She concluded that lack of access to basic resources directly impacts educational quality, and students outcomes, perpetuating cycles of disadvantage. Candidates also posed their own questions and used data analysis to investigate and answer them. Below is one example:

Question: Is there a correlation between the % of white students in a district and students' proficiency ELA and Math scores?

Data will be used for School districts 1-5.

Table For School Districts 1-5

	D1	D2	D3	D4	D5
White	15.7%	12.8%	26.3%	4.2%	7.3%
ELA Level 4	26.9%	22.3%	35.5%	24.5%	20.7%
Math Level 4	15.7%	11.7%	15.4%	15.1	8.5%

Source: NYC Open data

There is a strong correlation between ELA proficiency level 4 and % of White students in a school district, and a weak correlation between Math proficiency level 4 and % of White students.

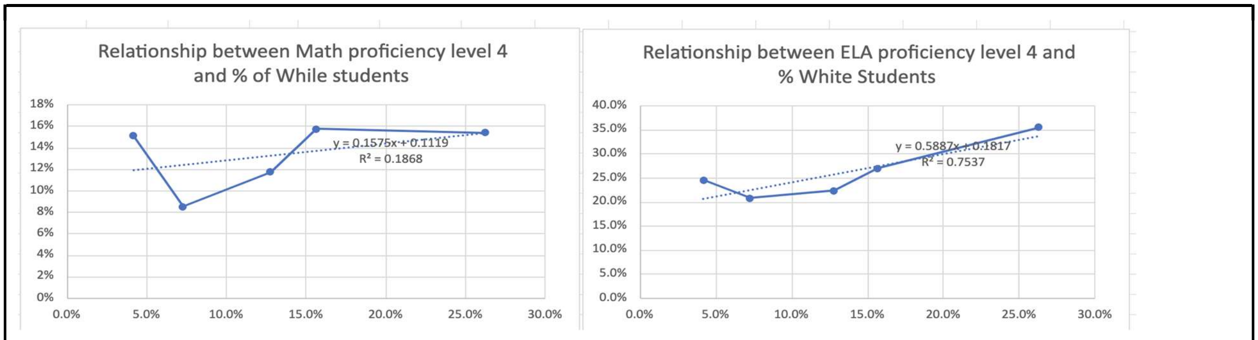


Figure 4: Excerpt from teacher candidate D's work on posing and answering their own question

Next, the teacher candidates explored the learning opportunities offered across various schools and districts, and in order to determine whether NYC students received the same quality of education. Based on their findings, the candidates determined that schools with predominantly Black and Latinx student populations often offered fewer Advanced Placement (AP) classes, had lower enrollment rate in AP classes, and had higher percentages of inexperienced or frequently absent teachers, as well and higher numbers of total days missed due to out-of-school suspensions. Two candidates found that their school offered no AP Mathematics classes, and that students' college readiness rate (measured by percentage of students graduating with test scores high enough to enroll at CUNY without needing remedial coursework) was well below the city average.
As part of their inquiry into educational equity, the candidates were also tasked to find out how much less total funding is allocated to school districts serving predominantly students of color compared to school districts serving predominantly white students at national level, and how these national findings compare to those in NYC. To do so, candidates researched their local school districts' budgets, using public records or local media such as newspapers or television reporting, and with determining the budget per student.

Candidates were also guided to summarize their findings by comparing data on local school budget, available learning opportunities, and teacher qualifications, with their prior research on segregation and student achievements. The goal of this comparative analysis was to determine whether data suggested correlation between some variables, such as the relationship between funding levels and educational outcomes. During class discussions, the candidates shared their reflections and key findings. Candidates commented that they were shocked to read that the differences in annual funding between nonwhite and white school districts nationwide amounts to 23 billion (EdBuild, 2019), which translates to a difference of $2300 per student.

One candidate, who explored the EdBuild database (2019), found that nonwhite school districts in New York State receive, on average, 10% less funding than predominantly white school districts. Additionally, she found that high-poverty white school districts receive about $4000 more per student compared to high-poverty nonwhite school districts. The visualization below, created by this candidate, illustrates these disparities, and initiated a deeper conversation about structural inequities in school funding.

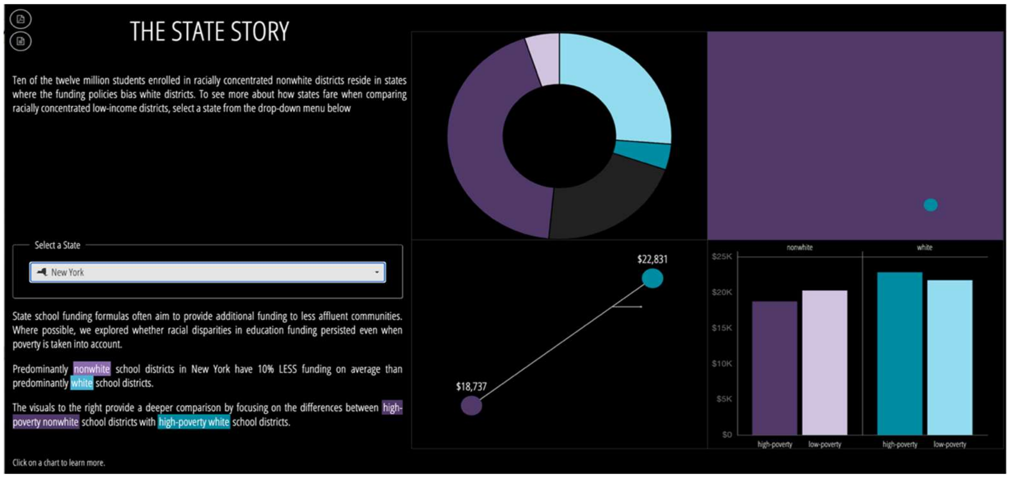
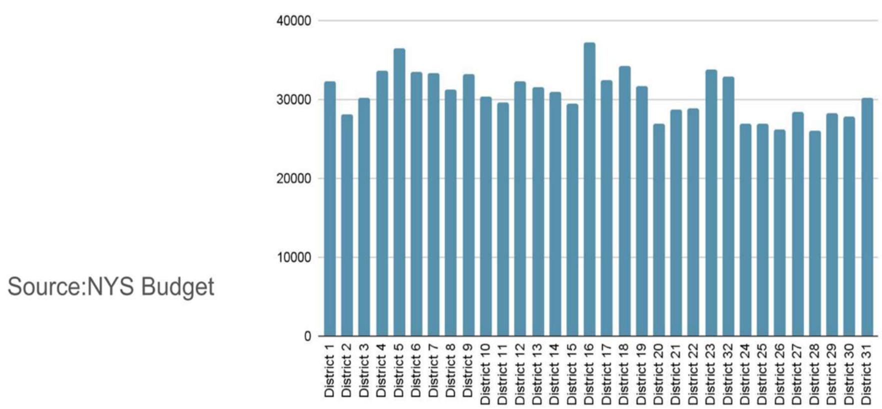


Figure 5: Teacher candidate E’s diagrams of high-poverty white and non-white school districts funding

Another teacher candidate shared his findings on the budget allocations within New York City school districts.



(https://openbudget.ny.gov/schoolFundingTransparency.html)

There is a large difference in funding between NYC school districts 5 and 16, for example, and districts 26 and 28.

Figure 6: Excerpt from teacher candidate F’s visualization of NYC school district budgets

Additionally, the candidates were also asked to formulate their own inquiry questions, explore the relevant data sets to investigate those questions, and then share their findings with the group. Close exploration of the data sets and analysis of relationships between variables such as race, teacher quality, suspensions, and educational opportunities such as AP courses, Computer Science Courses, and Gifted and Talented Programs, led the candidates to conclude that there is a clear correlation between race and educational opportunities.

Engagement with Coding and Data Analysis With R

The final session of the module was structured as an immersive workshop led by the second author. The purpose of this session was to introduce teacher candidates to R, a programming language for statistical computing and data analysis, allowing them to engage with data analysis through a different lens. This experience provided teacher candidates with new tools to engage with data analysis enabling them to revisit and further investigate some of the questions that the candidates had previously explored. The second author introduced candidates to R Studio. He guided candidates through the process of downloading R and RStudio, creating a free account, and setting up their workspaces. Candidates were then introduced to the NYC Department of Education (DOE) data available through the NYC Open Data portal. The session continued with instruction on using the Tidyverse—a collection of R packages designed for data manipulation and visualization. Through hands-on practice, candidates learned to sort, filter, and analyze large datasets and to generate visual representations of trends and relationships relevant to their research questions.

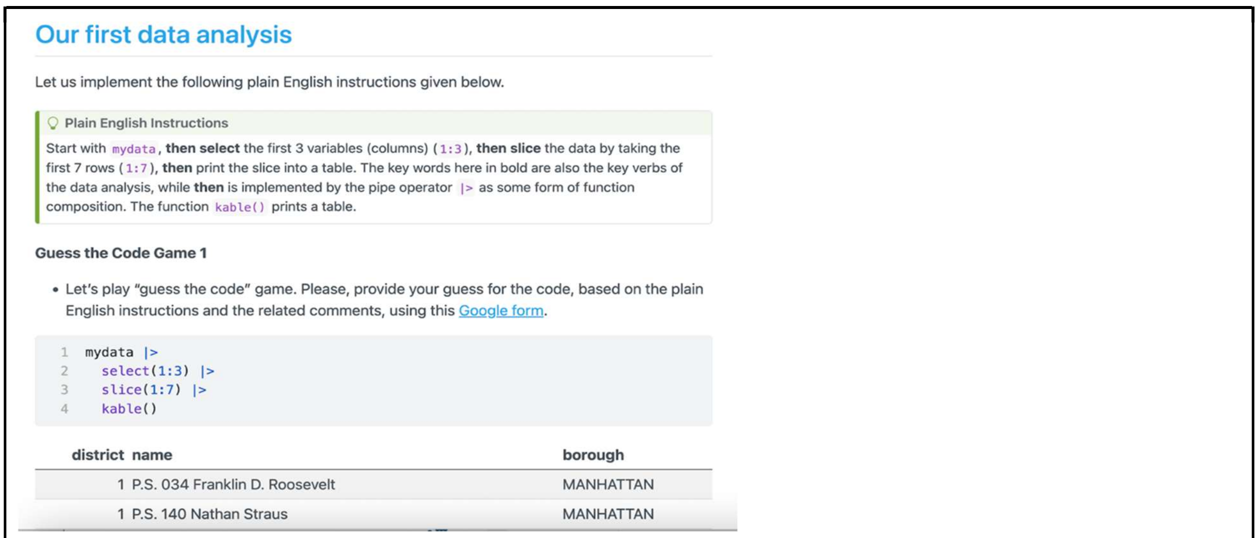


Figure 7: Excerpt from a collaborative "guess the code" exercise with R.

Next, the second author guided the candidates about filtering data.

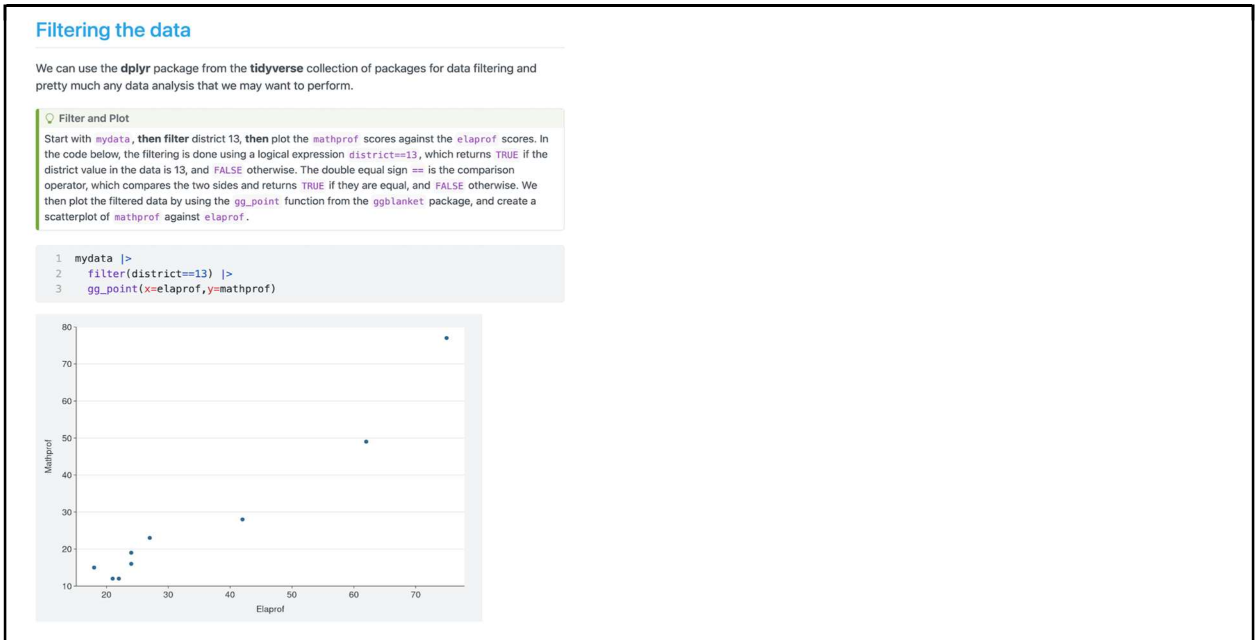


Figure 8: Excerpt from a collaborative filtering data exercise with R.

He then guided the candidates in exploratory data analysis to basic model fitting. The question that was explored was "Is there a relationship between student ELA proficiency and math proficiency?"

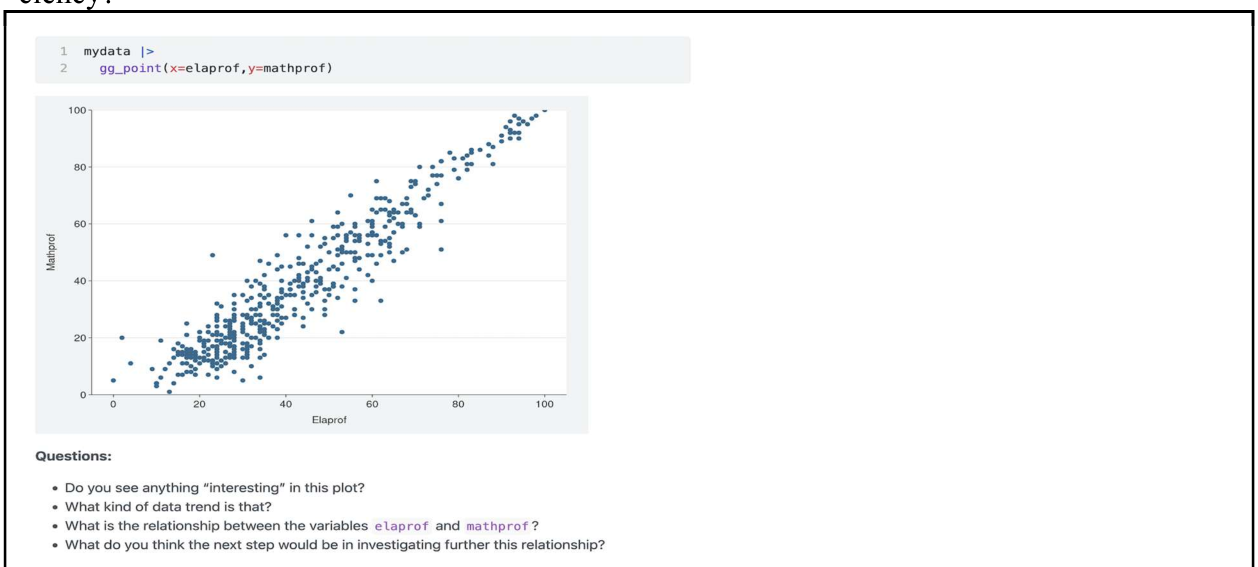


Figure 9: Excerpt from collaborative exploratory data analysis to model fitting

Finally, the candidates were guided in writing a code, which functioned to select a specific number of schools from the dataset and to create a chart documenting the percentage of students with math proficiency. The chart provided a visual representation of school-level variation in student achievement, demonstrating the importance of data visualization in identifying patterns and disparities within educational outcomes.

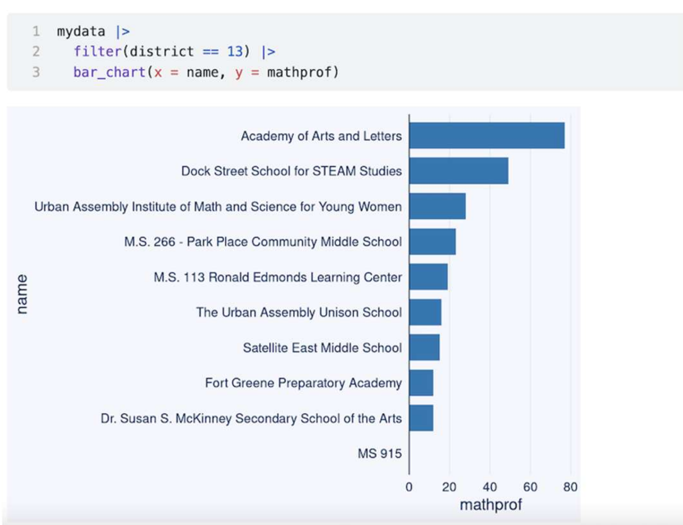


Figure 10: Excerpt from collaborative code writing for documenting students' math proficiency

Discussing "for" and "against" Uses of Big Data in Education

In the final phase of the module, the first author prompted the teacher candidates to reflect on the uses and limitations of technology and big data in education decision making. The discussion encouraged critical reflection on the limitations of data, and specifically on what data can and cannot capture, particularly in relation to students, schools, and communities. The candidates observed that important aspects of schools and student experiences are often absent from data sets, as the data reflects only information that the designers choose to collect. Because datasets are shaped by the interests, priorities, and assumptions of their creators, they may omit elements that others would consider essential. For example, one candidate expressed frustration that he was unable to find any data on extracurricular activities in the middle schools he was reviewing and comparing. Despite their significance in shaping school culture and student engagement, such qualitative features were not included in the available datasets.

The candidates also interrogated the assumptions embedded in data collection and visualization practices. Candidates observed that comparing schools based solely on quantitative data assumes that the schools are somewhat equivalent in relation to all "invisible dimensions," such as school climate, leadership, community engagement, or teacher expectations. They also noted that in the "standardization" of individuals in a data set, all featured students and schools lose their unique characteristics, reducing them to variables that can be measured, ranked and compared. Qualitative features such as school culture or teacher expectations are difficult if not impossible to quantify and cannot be captured in databases. Overall, candidates thought that data analysis was helpful and potentially advantageous but that it had to be used with care, and that the potential biases and limitations of datasets and data analysis needed to be kept in mind. They concluded that while data can be a powerful tool for equity-oriented decision-making, the importance of remaining mindful of biases, oversimplifications, and omissions cannot be overstated. Data must be interpreted critically and complemented by qualitative insights to account for the complexities and nuances of educational systems.

From Data to Critical Inquiry: Reflecting on Segregation, Inequity, and the Future of Public Education

Overall, the teacher candidates reported that combining data analysis with readings and collaborative discussions deepened their understanding of the schools where they were placed for field experience, as well as of the students in those schools. They appreciated the opportunity to compare their placement schools to others in New York City and across the nation. Many noted that they had developed practical skills for examining school data and were able to uncover important, and sometimes surprising, information. One candidate shared: *"I found [the data analysis] useful, because you can see all this bunch of data, but until you organize it you won't be able to understand it really. I found more information about the school I was in."*

Another reflected on his current school placement: *"What I found [about the school I'm at now] was that the majority of the teachers were not certified. I was really surprised—as they've been working there for years and still didn't have certification. And then I looked at how students were doing and compared that school with my previous placement, which was the second in District xxx [with the second-highest math proficiency level]. The current school—everyone says it's good—had very low math and ELL proficiency levels. But interestingly, the data showed its funding was higher than most schools in the neighborhood."*

In some cases, candidates reported that these new analytical skills influenced not only their development as educators but also their roles as parents or community members. One candidate shared: *"I have three kids in District x and I wanted to find more about the schools there… My daughter was going to middle school, and I wanted to know what kind of school she was going to. I learned a lot by looking at the data. I saw how wealthy the parents [in one school] were compared to the other two schools. I was shocked by the different economic level of the parents… and the school is whiter."*

The teacher candidates largely agreed that the data analysis activities revealed patterns of school inequity and segregation, as well as the negative impact these have on students from high-poverty or minoritized communities. As one candidate remarked: *"…for me, it helped me understand and see correlations as to why some schools have students who are struggling with math* *and others don't. It seems that it has a lot to do with literacy rates—the higher the literacy, the higher the math proficiency. I also found that schools with more white or Asian students tend to perform better than schools with more Latinx and Black students."*

Through data exploration, candidates discovered wide disparities in access to advanced coursework—particularly in Precalculus, Calculus, and AP courses—as well as extracurricular opportunities. These disparities correlated strongly with differences in school funding, teacher certification, student demographics, and geographic location. One teacher candidate concluded: *"I never believed there were such great differences between schools in NYS and the country. But with the data, I really had the chance to go inside it, and the data showed that equal opportunity in education doesn't exist."*

Other candidates noted how the process helped challenge long-held assumptions: *"I assumed those elite schools had more funding per student because students were performing better—but I was wrong. That isn't true. Maybe it was true back then, but when I looked at the data, they were getting $11K per student, whereas some of my neighborhood schools are getting around $30K per student."*

The close data analysis conducted by the teacher candidates, along with the various empirical questions they pursued, laid the groundwork for a broader and more critical inquiry around more general and philosophical questions such as: What repercussions do school segregation and educational inequity have for students in society? What are potential remedies for addressing school segregation and inequity? What is fair school funding and why does it matter?

Teacher candidates concluded that school segregation nowadays is driven by systemic inequality, and existing residential segregation in NYC (and the US) results in schools divided by race and socioeconomic status. The candidates' analysis led to the conclusions that segregation and inequity have a profound effect on minority students' learning outcomes and thus act to limit their future educational and job opportunities. The teacher candidates were asked to make an argument for what should— or should not —be done to make New York City's public schools more diverse and inclusive. Below are excerpts from several of their reflections.

Teacher Candidate C: *"If I were a mayor and had the power to change the NYC public education system of NYC, I would get rid of gifted & talented programs and elite high school programs. Those special schools would accept students without testing and would accept students that represent the community. If the community is diverse, the school should accept students whose composition mirrors the community."*

Teacher Candidate D: "*One thing that I would like to see change is the way schools are funded. If a school is located in a wealthy neighborhood or where the taxes are high, that school would have a better chance to receive more funds than a school in a poor neighborhood. Therefore, the first school will be more likely to recruit qualified and experienced teachers and have more* *school supplies. Moreover, the same school will have more resources such as a bigger library and better equipped computer labs. The current process of funding schools is outdated, not equitable and perpetuates school segregation. The government must reformulate the way schools are being funded, for example by using entirely federal funding. It is imperative for schools from low-income neighborhoods to receive sufficient funds in order to provide the necessary resources and supplies needed*."

Teacher Candidate H: "*New York City should make changes to ensure that every school accepts at least 15 percent of the students from every major ethnic group in the school neighborhood. This law should be applied to every elementary, middle, and high school to make sure students from different races and backgrounds are not excluded and get access to sufficient resources. Usually, students who aren't native English speakers struggle due to language barriers, therefore every school should also ensure additional support for those students. Furthermore, I also think that as we promote schools' diversity in NYC, we need more teacher diversity. We need to recruit teachers from different cultural backgrounds, whose presence may be important for students to build relationships and to be more successful*."

Mathematics Teacher Candidates Perceptions of the Potential of Computing and Data Analysis in Mathematics Teaching and Learning

Based on a focus group interview conducted after the completion of the course, we found that the teacher candidates' perceptions of the potential of computing and data analysis in mathematics teaching and learning, although overall positive, were nuanced and mixed. Several candidates thought that using real-world data sets in mathematics instruction could promote new and useful skills among students, equipping them to independently engage with data analysis in the future. A teacher candidate expressed the view that data analysis can be used by teachers to learn more about the student population one teaches. He noted: "…you can use data to learn more about the students [in your school] and understand better where they are coming from." Several candidates viewed data analysis as a promising pedagogical tool, capable of making math activities more relevant to students, and fostering engaging and meaningful discussions. They emphasized that integrating data-driven tasks could enhance mathematics lesson by connecting them to real-life issues-- such as poverty rates, student loans, and rising climatic temperature – and by helping students make sense of the world around them. It promises to provide relevance to students' lives, and may act to increase their motivation. One candidate commented: "One can bring social justice issues to the classroom, for example collaborate with the social study teacher and maybe they can do a study of neighborhoods or comparing schools." Another noted the potential for data to highlight inequities in STEM fields, stating: "[Data sets and analyses] could be used showing… because woman predominantly make up the smallest number of engineers, and Latinx women make the smallest number of women in STEM."

Several teacher candidates believed that engaging students in data analysis can introduce social justice issues, and can be empowering and lead to activism in their communities. As one remarked: “it [data analysis] helps students to know more about the world around them and can lead them to get involved in advocacy work.” The integration of computing and data analysis in the mathematics classroom was viewed not juts as a technical skill, but as a means to of developing a critical stance and provide a context for engaging with important social issues. However, some concerns were also expressed. One candidate voiced hesitation about addressing social justice issues through data analysis, remarking: “I don’t think I’ll use this specifically; I heard that there is push back in the schools if the lessons are too political.” Another reflected on the practical challenges of implementing data-driven lessons, including the time and effort to curate data sets, additional preparation to adapt lessons, as well as extra time needed for students working with data sets and analysis. The perceptions of most candidates were that using data analysis can enhance mathematics lessons and be worthwhile, but it may not be realistic in the first one or two years of teaching. In sum, candidates recognized the pedagogical and societal potential of computing and data analysis in mathematics education, particularly in promoting relevance and critical engagement. However, their reflections also highlighted the need for adequate support, time, and teaching experience in order to fully realize this potential in classroom practice.

DISCUSSION

Overall, out team found that the course module effectively engaged teacher candidates in data exploration and analyses related to NYC schools – particularly the schools where they were placed for field experience. The module succeeded in fostering critical discussions and equity-oriented inquiry through data. However, our reflections also pointed to several areas for improvement in future iterations. First, we observed that some candidates struggled with posing their own research questions and identifying the type of questions that could be meaningfully addressed though data analysis. More scaffolding is necessary in that regard in the next iteration of the module implementation. In general, we recommend that collectively exploration of data sets precede individual data analysis. In the next iteration of the module implementation, instructors should model question posing and data analysis before assigning individual assignments. This shared experience can build candidates’ confidence and understanding before moving into individual or small-group work.

Second, we found that introducing R and RStudio required more time and support than the course schedule allowed. Thus, we think it would be more appropriate that a next iteration of the teaching module use CODAP for data analysis rather than R. Some module activities have been modified to utilize CODAP. Our experimentation shows that R studio would need more time to introduce, and that more than one course might be necessary for teacher candidates to begin comfortably using it for data analysis and computational modeling. While R is a powerful tool for data analysis, we found that it may not be the most accessible platform for all students—particularly within the limited timeframe of a multi-week module. Based on our experience with the first iteration of the module, we recommend using CODAP (Common Online Data Analysis Platform) for future implementations. CODAP provides a more user-friendly and intuitive environment for beginners, while still supporting meaningful engagement with data analysis.

Activity 4 of the course module has already been revised to incorporate CODAP (see Appendix for details), although the adapted version is yet to be implemented in the next module cycle. This CODAP-based activity uses NYC School Open Data to help teacher candidates visually and analytically explore educational issues. Integrated into a math education course, it promises to help teacher candidates builds skills in data analysis and visualization, raise awareness of equity gaps, and prepares candidates to apply data-driven approaches in their teaching. We believe this adaptation will enable teacher candidates to engage more deeply in independent inquiry and data interpretation by reducing the technical barriers associated with learning R.

CONCLUSIONS

This study examined the implementation of a course module which integrated computing and data analyses into a mathematics education course. Designed for prospective mathematics teachers, the module engaged candidates in exploring datasets to better understand their field placement contexts, and support them in developing data analysis and critical thinking skills. Candidates engaged in topics related to student learning opportunities, achievement gaps, school segregation, and broader issues of education (in)equity and social justice. The module emphasized a commitment to equity, and encouraged deep explorations of these topics through texts, data analysis, collaborative discussions, and direct experience. By sharing and reflecting on their findings, candidates developed a deeper understanding of the principles and uses of data analysis in addressing issues of social justice, and of its potential role in the mathematics classroom.

ACKNOWLEDGMENTS

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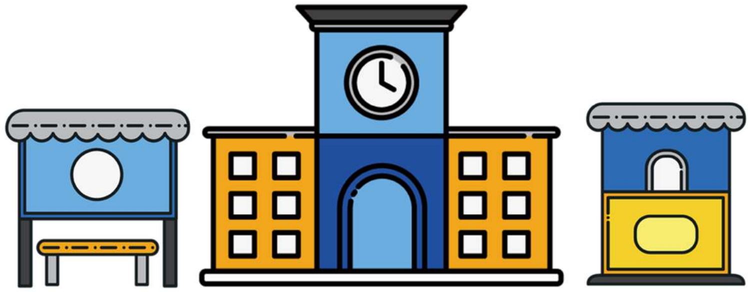
APPENDIX

Course Module: Behind the Data: Analysis and Visualization of School and Student Data

Activity 1: Warm-Up: Visualize Data

Visual Portrait of Your School: Learn about Your Field Experience School and School District



Source: Pixabay

Search through the NYC, NYS and national education data bases below and search for information about your school and about your school district.

Additionally:
Scroll down to the interactive map of the United States in the Miseducation (ProPublica) database and then answer the following questions:
1. Click the tabs "Opportunity," "Discipline," "Segregation" and "Achievement Gap" and answer these two questions: What do you notice? What do you wonder about?
2. Next, click the tabs "Black" and "Hispanic." What do you notice? What do you wonder?
3. Search for your school or district in the database. What do you notice in the results? What questions do you have?

Explore the Civil Rights Data Collection and check:
- School and district search
- Detailed data tables
- Data analytic tools
- Special reports for schools and districts (English Language Learner report, discipline report, education equity report, state and national estimations)

Assignment:
Prepare a report (minimum 1 page) on what you have found about your school and about your school district. In your reflection, include detailed results, e.g., "School district ….'s composition is 24 % Black, 41%, Hispanic, 16% White, 17% Asian, 1% Native American, 1% Two or more races." Or "White students are 1.7 times more likely to be enrolled in at least one AP class as Black students." Include graphs and tables from the database. Be ready to share your findings in class.

Possible Data Sources to Use

Key National Education Data Sources

Data Source	What It Covers	Why It's Useful	Link
Common Core of Data (CCD) – NCES	Public elementary & secondary schools & districts: enrollment, staff, school types, fiscal data. NCES	Good for longitudinal and cross-state comparisons of K-12 schooling.	CCD, NCES NCES
EDFacts	PreK-12 data submitted by state education agencies: demographics, performance & assessments, program participation, funding/grants data. U.S. Department of Education+2U.S. Department of Education+2	Centralized source for many metrics at school and district level. Useful for policy analysis, funding, accountability.	EDFacts Initiative U.S. Department of Education
NCES / Administrative Data Collections	NCES collects non-fiscal and fiscal data about K-12 via CCD; other state/local K-12 and postsecondary data as well. NCES+1	For basic data: student counts, school/district descriptors, finances, staffing.	NCES Administrative Data Collections NCES
National Assessment of Educational Progress (NAEP)	Nationally representative assessments in reading, math, science etc.; long-term trends in student achievement.	Strong source for understanding achievement over time, comparing states.	Available via the U.S. Department of Education / NCES "Nation's Report Card" portal. (via ED Data / NCES) U.S. Department of Education
Open Data Platform / U.S. Department of Education	Multiple datasets: civil rights data, school finance, performance, student outcomes, etc. U.S. Department of Education+1	Good starting place for locating various national-level datasets in one place.	ED's Open Data Platform U.S. Department of Education
Office for Civil Rights' Data on Equal Access to Education	The Civil Rights Data Collection (CRDC) is a mandatory survey conducted by the U.S. Department of Education's Office for Civil Rights. It covers public schools (pre-K through grade 12) in all 50 states, Washington DC, and Puerto Rico.	It is biennial (collected every two years), gathering information on a wide array of indicators relevant to civil rights in education — whether students of different races, sexes, abilities, etc., get equal educational opportunities.	Civil Rights Data Collection (CRDC)
Miseducation (ProPublica)	Covers nearly all public and charter schools in the U.S., it allows comparisons across and within states, districts, and schools.	Focuses on equity and racial disparities	Miseducation (ProPublica)

New York State (NYSED) Data Sources

Data Source	Link	What It Offers
NYSED Data Site	data.nysed.gov New York State Education Department Data	Public reporting of educational data for NY: student & school data, etc. New York State Education Department Data
School & District Account-	NYSED Accountability & ESSA data	State accountability data under ESSA: perfor-

Data Source	Link	What It Offers
ability Resources and Data (ESSA)	New York State Education Department	mance, reporting, etc. New York State Education Department
Basic Education Data System (BEDS)	NYSED / IRS / BEDS New York State Education Department	Institutional school/district master data, enrollment, staffing, etc.

NYC / Local NYC Public Schools Data Sources

Data Source	Link	What It Offers
School Quality Snapshots	NYC School Quality Snapshots via NYC Schools website	Summary reports of school environment & student achievement, etc.
NYC School Survey	NYC School Survey web	Feedback from families, students, and staff on school environment, etc.
NYC InfoHub – School Quality Reports & Resources	NYC School Quality Reports & Resources InfoHub	Multi-year school performance data, visualizations; guides; downloadable data. InfoHub
NYC Insights & Reporting / Data at a Glance	NYC DOE Insights & Reporting web	Snapshot summaries, reports on student population, etc.
NYC Open Data	NYC Open Data website	Free public data published by NYC agencies and partners

In-Class

Gallery Walk

Teacher candidates share their findings.

Discussion Questions:

- What did you find about your school/school district?
- Do all students in NYC receive the same quality of education?
- Do all students in America receive the same quality of education?
- Do you think that there is a correlation between students' race and the quality of education they receive?
- What is the purpose of public education?
- Is receiving a quality public education a right (for everyone) or a privilege (for some)

Activity 2: (In)equitable School Funding

Investigate relationships between school funding, inequity, and achievement

Source: Pixabay

Readings for the session:

EdBuild (2019). *23 Billion*. https://edbuild.org/content/23-billion
Lombardo. C. (2019). *Why white school districts have so much more money*. https://www.npr.org/2019/02/26/696794821/why-white-school-districts-have-so-much-more-money.

Mervosh, S. (2019). How much wealthier are white school districts than nonwhite ones? $23 Billion, reports. *New York Times*, https://www.nytimes.com/2019/02/27/education/school-districts-funding-white-minorities.html

Assignment:

Choose one of the following ideas (or generate another) to investigate the interrelationship among school segregation, funding and inequality.

1. Research your local school district budget, using public records or local media, such as newspapers or television reporting. What is the budget per student? How does that budget compare with the state average? The national average?
2. Compare your findings about your local school budget to your research about segregation and student achievements, using the Miseducation database. Do the results of your research suggest any correlations?
3. Prepare a report and share with peers.

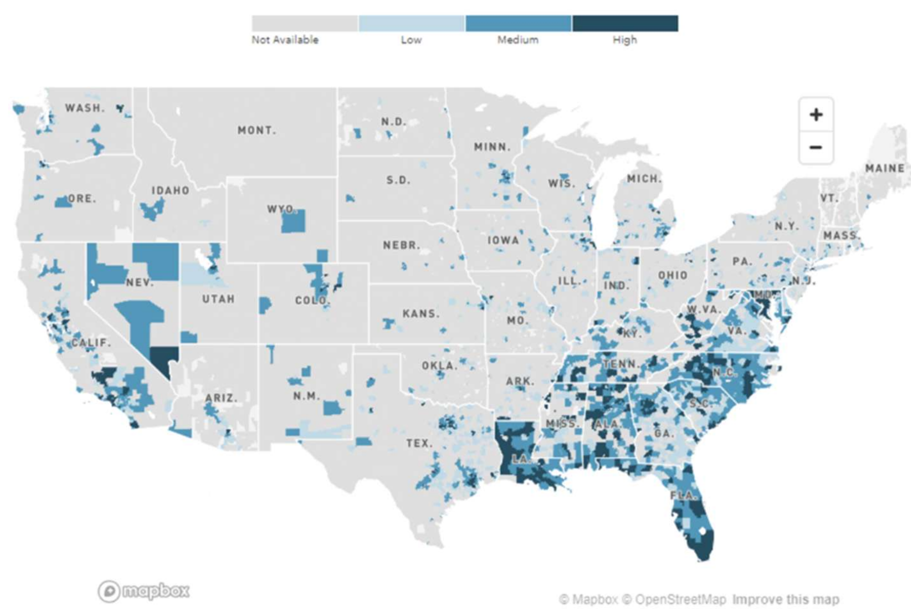
Discussion Questions:

1. How much less total funding do school districts that serve predominantly students of color receive compared to school districts that serve predominantly white students?
2. Why are school district borders problematic?
3. How many of the nation's schoolchildren are in "racially concentrated districts, where over 75

percent of students are either white or nonwhite"?
4. How much less money, on average, do nonwhite districts receive than white districts?
5. How are school districts funded?
6. How does lack of school funding affect classrooms?
7. What is fair school funding and why does it matter?

Activity 3: Segregation and Educational (In)equities

Investigate the relationship between segregation, educational opportunities, and (in)equities



Using the original interactive map on ProPublica, you can search for individual school districts and change data categories by race and measure.

Image from ProPublica

Readings for the session

Readings: NYC Schools (In)Equity
Read at least two of the articles below:

Lefty, L. (2021). *The long fight for educational equity in NYC*. Retrieved from https://www.mcny.org/story/long-fight-educational-equity-nyc on August 1, 2022.

Futterman, K. (2020). *Education and equality in NYC: The problem at hand*. Retrieved from https://polygonnews.org/2299/showcase/education-and-equality-in-nyc-the-problem-at-hand/ on August 7, 2022.

Robinson, G. (2013). *Class in the classroom: The income gap and NYC's schools*. https://citylimits.org/2013/09/25/class-in-the-classroom-the-income-gap-and-nycs-schools/ on August 1, 2022.

Readings: School Segregation (In NYC, America and Abroad)
Read at least one of the articles below:

Gould, J. (2021). *New York's schools are still the most segregated in the nation: Report*. Retrieved from https://gothamist.com/news/new-yorks-schools-are-still-the-most-segregated-in-the-nation-report on July 25, 2022.

Hannah-Jones, H. (2016). Choosing a school for my daughter in a segregated city, *New York Times Magazine*, https://www.nytimes.com/2016/06/12/magazine/choosing-a-school-for-my-daughter-in-a-segregated-city.html

Shapiro, E. (2019). Facing segregated schools, parents took integration into their own hands. It's working, *New York Times, https://www.nytimes.com/2019/04/16/nyregion/new-york-city-school-segregation.html*

Shapiro, E. (2021). Lawsuit challenging N.Y.C. school segregation targets gifted programs, *New York Times*, https://www.nytimes.com/2021/03/09/nyregion/nyc-schools-segregation-lawsuit.html

School Segregation in Other Countries
Read at least one of the articles below:

Surk, B. (2018). In a divided Bosnia, segregated schools persist, *The New York Times*, https://www.nytimes.com/2018/12/01/world/europe/bosnia-schools-segregated-ethnic.html

Maragkidou, M. (2015). Segregation, bullying and fear: The stunted education of Romani children in Europe. https://www.amnesty.org/en/latest/news/2015/04/the-stunted-education-of-romani-children-in-europe/

Assignment:

1. Only a tiny number of black students are admitted to the highly selective public high schools in New York City (e.g., 2019, 2020, 2021) raising the pressure on officials to confront the decades-old challenge of integrating New York's elite public schools. To learn more about this story, listen to this episode of The Daily. For more information, read this essay offering different perspectives on the problem and possible solutions.

Make a case for what should be done — or not done — to make New York's elite public schools more diverse.

2. Pose a question in relation to NYC school segregation and inequities that you would like to answer. Use NYC Open database https://opendata.cityofnewyork.us/ to find an answer to your question. Be ready to share in class your question, results of your research and visual representations.

Gallery Walk

Share your findings.

Discussion Questions:

- How and why are schools still segregated in 2022 (in NYC, America and the world)?
- What repercussions do segregated schools have for students and society?
- What are potential remedies to address school segregation?

Activity 4: Using R for Data Analysis and Discussions of Data Bias

Free image from Pixabay

Readings for the session:

Haagort, M. (2021). *Every database is biased*. https://becominghuman.ai/every-database-is-biased-6a402224b8a9.

R- Workshop Structure

The workshop is framed as a hands-on introduction to exploratory data analysis (EDA) using R and RStudio (now Posit). It is organized into the following stages:

1. Introduction – Setting goals (working with NYC DOE middle school data) and setting up R/RStudio/Posit.
2. Loading the Data – Importing via API with RSocrata or via CSV download with readr.
3. Preparing the Data – Selecting relevant variables from a large dataset (327 → 18 variables).
4. Exploratory Data Analysis – Using Tidyverse pipelines (dplyr, ggblanket, ggcharts) for filtering, slicing, selecting, and visualizing.
5. Progressive Practice ("Guess the Code" Games) – Translating plain English instructions into R code.
6. Modeling – Moving from scatterplots to regression (line of best fit).
7. Advanced Analysis – Sorting, mutating variable types, filtering, and producing ranked tables and bar charts.

The Data

The data comes from the 2021 DOE Middle School Directory (NYC Open Data Portal).

Size**:** 474 rows (schools) × 327 columns (variables).

Selected Variables (18 used): district, name, borough, latitude, longitude, diversityinadmissions, coursepassrate, elaprof (ELA proficiency), mathprof (Math proficiency), surveysafety, totalstudents, gradespan, acceleratedclasses, electiveclasses, languageclasses, tophs1, tophs2, tophs3.

Questions Explored

Participants investigate progressively deeper questions such as:

Basic exploration

- What are the first few schools in the dataset?
- How do district and borough variables look in small slices of data?

Filtering

- What happens when you plots Math vs. ELA proficiency with and without filtering by district?
- What trends or relationships exist between ELA and Math proficiency?

Exploring Relationships and Modeling

- Is there a linear relationship between Math and ELA proficiency?
- How do we calculate the center of mass and fit a regression line?
- How can the regression line be used to make predictions?

Advanced exploration

- Which schools have the highest math proficiency scores?
- Which schools have the lowest survey safety ratings?

- How do results compare across boroughs and districts?
- What does filtering on surveysafety or mathprof reveal about specific districts (e.g., District 13)?
- Which middle schools send the most of their students to the specialized math and science high schools in?

Coding Approach

Packages used: RSocrata, tidyverse, ggcharts, ggblanket, knitr

Workflow:

Import → Select → Filter → Summarize → Arrange → Slice → Visualize.

Heavy use of *pipes* **(|>)** for chaining steps in plain English style.

Type handling with mutate(as.numeric()) when variables import as characters.

Pedagogical technique: "Guess the Code" games encourage learners to translate natural-language tasks into R pipelines.

Visualization Techniques

Tabular outputs: knitr::kable() for clean tables.

Scatterplots: gg_point() to explore relationships (ELA vs. Math).

Regression fits: gg_smooth(method="lm") with overlays (line of best fit, center of mass)

Bar charts: bar_chart() for safety and proficiency comparisons across schools.

Data slicing: visual confirmation of subsets (e.g., top-performing schools, low-safety schools).

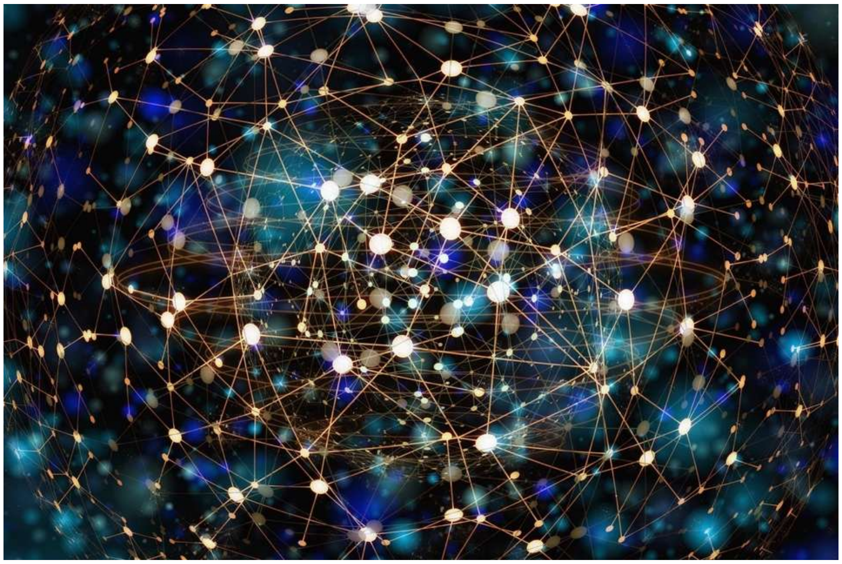
Overall, the workshop combines data literacy (interpreting variables), coding practice in R (tidyverse pipelines), and visual reasoning (plots + regression), and is structured as an engaging exploratory activity on NYC school data for mathematics teacher candidates.

Discussion Questions:

1. What is bias?
2. Could a database be biased? Explain.
3. If so, what might be some sources of bias?
4. What can introduce bias in data representation and interpretation?
5. What can guard against bias?
6. In what ways data technologies/ data analytical tools can be helpful?
7. Are there ways in which data technologies/ data analytical tools be harmful?
8. What is the impact of data technologies on society and individuals?

Activity 5: Using CODAP for Data Visualization and Analysis with NYC Open database

(May be used as an addition or alternative to Activity 4)



Free image from Pixabay

CODAP Activity

Explore this interactive CODAP activity to analyze mathematics achievement data from New York City schools. Investigate patterns, compare neighborhoods, and uncover equity gaps using real-world data and dynamic visualizations.

https://codap.concord.org/app/static/dg/en/cert/index.html#shared=https%3A%2F%2Fcfm-shared.concord.org%2FqL13dtOqVcnqN6hnredH%2Ffile.json.

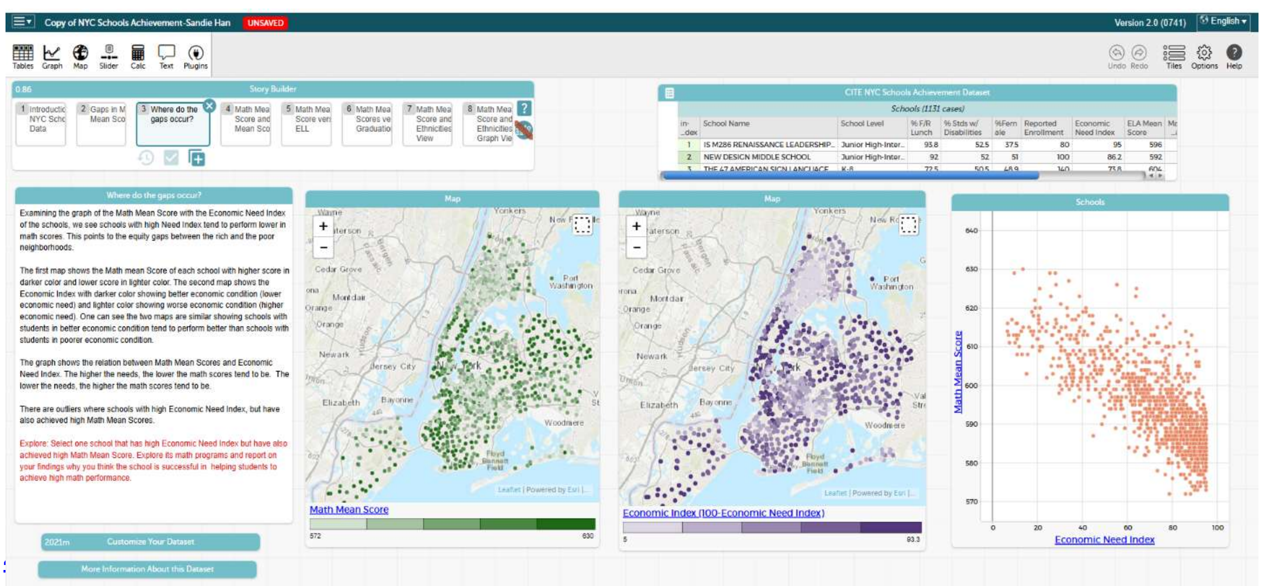


Figure 11: A CODAP activity exploring mathematics achievement gaps across New York City schools.

Following the activity, teacher candidates are encouraged to reflect on the following discussion questions:

Discussion questions:

1. What do the schools near City Tech look like in terms of selected characteristics (accessibility, course pass rate; ELA and math proficiency, total # students, graduation rates, ELL programs, other features, accelerated classes (APA classes), elective classes, survey safety) in comparison to schools in other neighborhoods (Manhattan, Brooklyn, Park Slope; Bronx)?
2. Can any inferences be made about what may account for learning gaps and differences in learning achievements?
3. What are some potential barriers or challenges to student success in mathematics and overall academic achievements in New York City schools, particularly in high-needs schools?
4. What evidence-based approaches/strategies may help improve the mathematics skills/engagement among students in high-need schools?
5. How would you design culturally responsive pedagogy to engage students in mathematics learning?
6. What activities would you design to increase students' interest and engagement in computational thinking and data analysis?

Course Module Readings

EdBuild (2019). *23 Billion*. https://edbuild.org/content/23-billion

Futterman, K. (2020). *Education and equality in NYC: The problem at hand.* https://polygonnews.org/2299/showcase/education-and-equality-in-nyc-the-problem-at-hand/ on August 7, 2022.

Hannah-Jones, H. (2016). Choosing a school for my daughter in a segregated city, *New York Times Magazine*, https://www.nytimes.com/2016/06/12/magazine/choosing-a-school-for-my-daughter-in-a-segregated-city.html

Lefty, L. (2021). The long fight for educational equity in NYC. https://www.mcny.org/story/long-fight-educational-equity-nyc on August 1, 2022.

Lombardo. C. (2019). *Why white school districts have so much more money*. https://www.npr.org/2019/02/26/696794821/why-white-school-districts-have-so-much-more-money.

Maragkidou, M. (2015). Segregation, bullying and fear: The stunted education of Romani children in Europe. https://www.amnesty.org/en/latest/news/2015/04/the-stunted-education-of-romani-children-in-europe/

Mervosh, S. (2019). How much wealthier are white school districts than nonwhite ones? $23 Billion, Report Says. *New York Times*, https://www.nytimes.com/2019/02/27/education/school-districts-funding-white-minorities.html

Gould, J. (2021). *New York's schools are still the most segregated in the nation: Report.* https://gothamist.com/news/new-yorks-schools-are-still-the-most-segregated-in-the-nation-report on July 25, 2022.

Robinson, G. (2013). *Class in the classroom: The income gap and NYC's schools*. https://citylimits.org/2013/09/25/class-in-the-classroom-the-income-gap-and-nycs-schools/ on August 1, 2022.

Shapiro, E. (2019). Facing segregated schools, parents took integration into their own hands. It's working, *New York Times, https://www.nytimes.com/2019/04/16/nyregion/new-york-city-school-segregation.html*

Shapiro, E. (2021). Lawsuit challenging N.Y.C. school segregation targets gifted programs, *New York Times, https://www.nytimes.com/2021/03/09/nyregion/nyc-schools-segregation-lawsuit.html*

Surk, B. (2018). In a divided Bosnia, segregated schools persist, *The New York Times*, https://www.nytimes.com/2018/12/01/world/europe/bosnia-schools-segregated-ethnic.html

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Using Digital Tools and Real-Life Interactive Activities to Teach Trigonometric Functions

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Abstract: Achieving meaningful educational outcomes requires scalable strategies for mastering mathematical concepts and skills, with student engagement at the core. This paper examines the use of comprehensive, technology-enhanced activities designed to promote active learning and deeper conceptual understanding. Specifically, it focuses on the integration of Desmos, an online graphing calculator, into mathematics instruction. The study explores whether combining Desmos with a hands-on approach to teaching trigonometric functions helps students connect abstract concepts to real-world applications. Findings underscore the effectiveness of digital tools like Desmos in increasing student engagement and improving student performance—particularly in the context of graphing and interpreting trigonometric functions.

Keywords: Student engagement, student performance, real-world mathematical application problems, Desmos activities, trigonometric functions

INTRODUCTION

In teaching mathematics, a key objective is identifying students' challenges and designing effective resources, methodologies, and assessments to close learning gaps, making education more equitable and inclusive. This manuscript focuses on teaching experiences in a College Algebra and Trigonometry course, where many students face challenges with graphing and interpreting trigonometric functions especially in the context of real-world applications.

A research project conducted during the Fall 2022 and Spring 2023 semesters investigated whether using the Desmos online graphing calculator helps students understand, visualize and interpret trigonometric functions and especially in the context of real-world problems. The Algebra and Trigonometry course's learning objectives, outlined in the department syllabus, emphasized making connections between real-life problems and formulas, graphs, or tables. These objectives also included solving problems using algebraic, numerical, or graphical methods, and employing tools like Desmos.

Multiple assessments were used, including pre-tests, post-tests, final exam questions focused on trigonometric functions and overall exam results.

This manuscript examines the benefits of integrating Desmos into lessons that incorporate real-life applications and graph transformations, using an active learning approach. Desmos allows instructors to design interactive activities, embed media, ask questions, and provide feedback. Students can manipulate graphs, share answers, and collaborate, while instructors can monitor progress and facilitate discussions through the platform's dashboard. The investigation focuses on the teaching and learning of trigonometric functions, given their well-documented difficulty for students. The purpose of this study is to determine whether the use of the Desmos online graphing calculator enhances students' understanding, visualization, and interpretation of trigonometric functions, particularly in the context of real-world problems.

LITERATURE REVIEW

This study is informed by constructivist theory (e.g., Steffe & Gale, 1995), and problem-based learning (Hmelo-Silver, 2004), all of which emphasize meaningful, collaborative community engagement and meaning-making. It is also influenced by current understandings of how people learn (Bransford et al., 2000) and the importance of active learner engagement with tasks. Active learning, as Bonwell & Eison (1991) suggest, encourages engagement through problem-solving, discussions, and group work. Freeman et al. (2014) found that active engagement with problem-solving enhances both student comprehension and performance. Contextual learning, rooted in situated learning theory (Lave & Wenger, 1991), stresses that knowledge is more effectively acquired when it is embedded in real-world contexts. This approach is also central to problem-based learning (PBL), where students engage with real-world situations to apply their knowledge (Barrows & Tamblyn, 1980; Hmelo-Silver, 2004).

In the evolving landscape of higher education mathematics, digital tools have become essential for enhancing student engagement, conceptual understanding, and real-world application of abstract ideas (Hoyles, 2018). Among these tools, Desmos has emerged as a transformative platform for teaching function transformations and graphing in courses such as College Algebra, Precalculus, and Calculus. By offering dynamic, interactive visualizations, Desmos enables students to immediately see the effects of modifying parameters within function equations, deepening their intuition about shifts, stretches, reflections, and compressions (Mane, 2025). Research shows that utilizing Desmos not only improves students' graphing skills but also fosters inquiry-based learning and critical thinking (Chechan et al., 2023).

The benefits of incorporating Desmos into higher education mathematics courses extend beyond visualization. Desmos supports collaborative learning, offers immediate feedback, and allows for exploration of complex mathematical behaviors in an accessible and engaging way. Studies have found that students using Desmos perform better on tasks involving graph interpretation and transformation compared to those using traditional methods (Pinheiro & Ippolito, 2021). Furthermore, Desmos' Activity Builder (Desmos, 2025b) can facilitate deeper understanding by guiding students through scaffolded explorations of mathematical concepts (e.g., see Desmos, 2025a, Unit 1: Benefits of Utilizing Desmos). By integrating Desmos into higher education curricula, instructors not only bridge the gap between abstract mathematics and tangible understanding but also cultivate a more equitable and engaging learning environment for diverse student populations.

METHODS

Study Context

The study compares two sections of the Algebra and Trigonometry course taught in Fall 2022 — MAT 115.C28 and MAT 115.C58. The first one actively used Desmos, and the second one did not use Desmos. In Spring 2023, another two sections were compared — MAT 115.C42, which used Desmos and MAT115.C55, which did not use Desmos.

The purpose of the study was to determine whether students from the course sections that used Desmos and Desmos activities performed better on questions related to graphing and interpreting trigonometric functions in the context of real-word applications. The research question that the study focuses on is: RQ: How does the use of Desmos impact student performance on trigonometric function problems, compared to traditional instruction?

The activities focused on graphing functions such as *(1)* $f(x) = a \cdot sin(bx - c) + d$*, and (2)* $g(x) = a \cdot cos(bx - c) + d$, function transformations, and interpretations in the context of real-world applications. All classroom activities were structured to promote best practices and inclusive learning across all course sections during each semester. In the sections using Desmos, Desmos was utilized to engage students interactively, allowing students to perform dynamic visualizations and to receive real-time feedback on graphing transformations. This helped students manipulate equations and see instant changes. It also helped the creation of a collaborative and exploratory, hands-on learning environment. The visual and interactive elements allowed students to explore mathematical ideas, with the instructor guiding their progress through the Desmos dashboard.

In contrast, the sections that didn't utilize Desmos followed a more traditional approach, where students used manual graphing of functions using graph paper and/or TI-83 or TI-84 Plus calculators. While this approach reinforced precision in calculations and graphing techniques, it lacked the immediacy of visual representations and feedback that Desmos afforded.

A typical classroom format for the sections which used or didn't use Desmos included the following practices:

1. Students watched an assigned video before coming to class.
2. A short pre-test was administered in the beginning of the class.

3. Students worked on classroom activities involving real-world applications.
4. Students were assigned to complete a homework assignment after the class.
5. Post- test was administered in the beginning of the following session for all classes.
6. Both sections of the course followed the same class format except that one of the sections worked on the classroom activities with Desmos, the other section completed the activities without using Desmos.

Below there are some of the challenges of a designed Desmos activity used in all class sections:

Desmos Activities

The following activities were designed to explore *graphing trigonometric functions of the form: (1)* $f(x) = a \cdot sin(bx - c) + d$*, (2)* $g(x) = a \cdot cos(bx - c) + d$*, where a,b,c,d are real numbers.*

1- Watch the video "The Ferris Wheel Rotation and Periodic Trigonometric Functions" as an introduction to make connections between trigonometric functions and some real-world applications. Explore and share other examples of trigonometric functions. (https://travelaway.me/most-famous-ferris-wheels/).

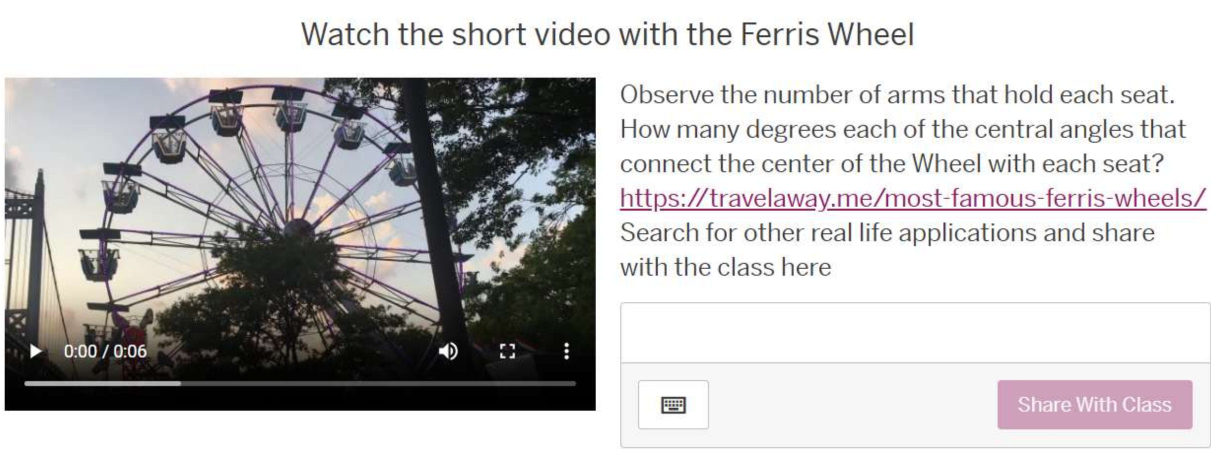


Figure 1: Ferris Wheel video

2- Observe the rotation of the Ferry Wheel and the position of a person seating in one of the seats (a point). (Observe both counterclockwise rotation and clockwise rotation). Determine the domain and the range of sine and cosine functions. (Students utilize sliders in Desmos to manipulate and observe the rotations, graphing, and transformations of sine and cosine functions)

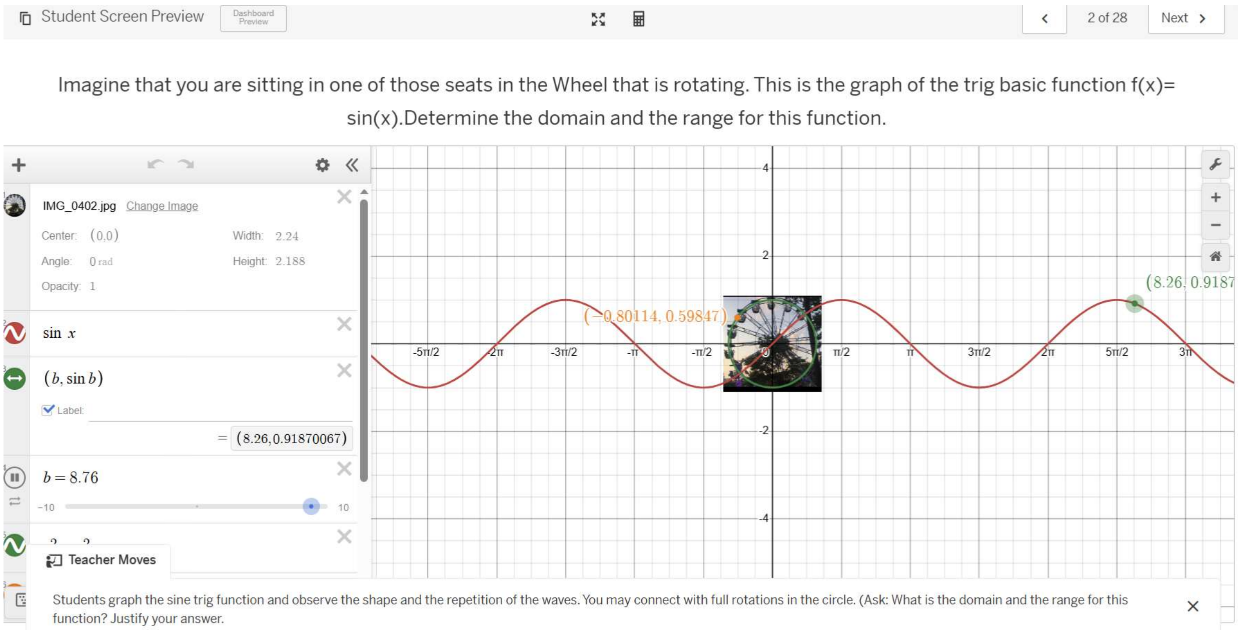


Figure 2: Connecting Ferris Wheel rotation to sine functions

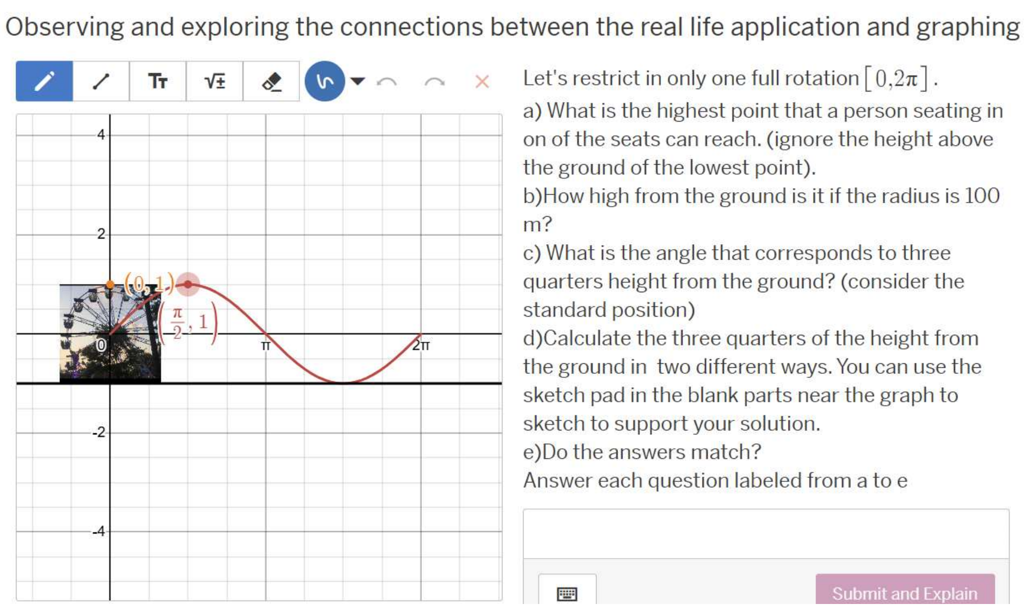


Figure 3: Exploring sine functions with Desmos

Graph the trig function f(x)=sin(x) in one period (cycle). Create a table with only the key points (label them). (starting, ending, zeros, intercepts, max, min). What is the section width?

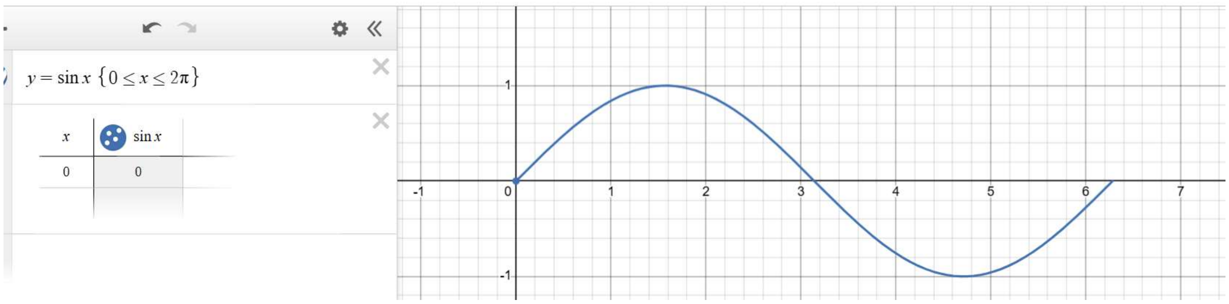


Figure 4: Graphing a sine function and connecting to a table with key points on the graph

3-

Observe the graphs of the trig functions f(x) =sin (x), g(x)=2 sin (x). You will be asked next slide for some features of the graphs.

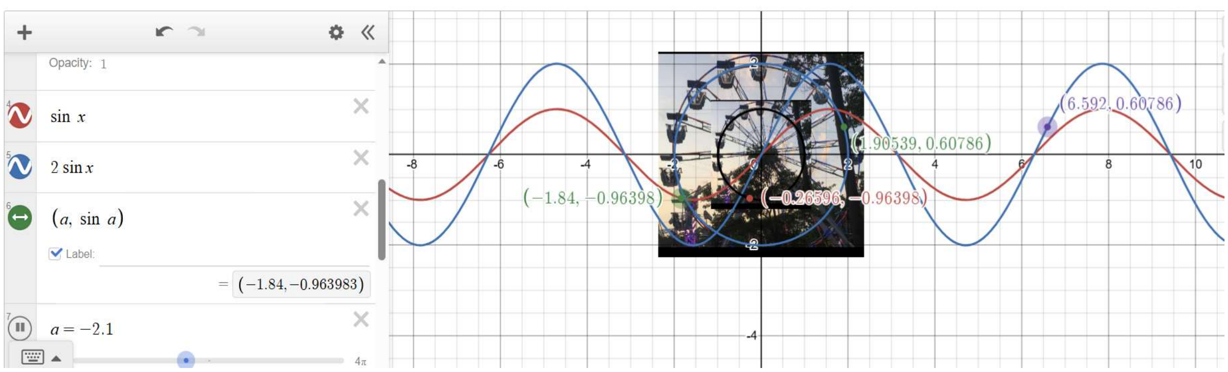
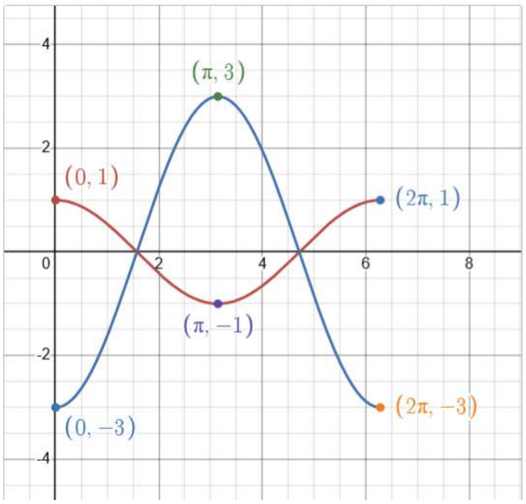


Figure 5: Comparing f(x) = sin(x) and g(x)= 2sin(x)

4-

Exploring the amplitude of cos function



The trig functions $f(x) = \cos(x)$, *and* $g(x) = -3\ \cos(x)$ *are graphed* for *you*.

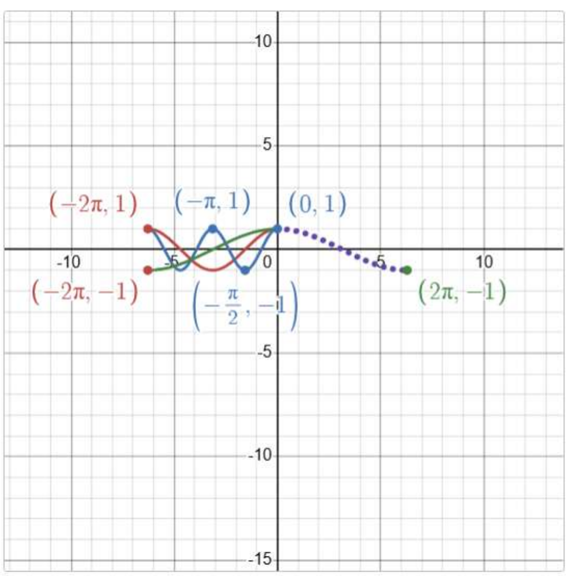
1) Find the amplitude for each of the functions.
2) Does the amplitude affect the domain or the range of the function?.
3) What are the parameters of the reference rectangle for the function $f(x) = 5\cos(x)$

Share With Class

Figure 6: Exploring the amplitude of f(x) = cos(x)

5-

Revealing the formula for finding the period of a function in form; y=Asin(Bx) or y=ACos(Bx)



How many waves are from each graph within the same interval $[2\pi,0]$.

$y = \cos\ x\ \ \{-2\pi \le x \le 0\}$

$y = \cos\ x\ \ \{-2\pi \le x \le 0\}$

$y = \cos\left(\frac{1}{2}x\right)\ \{-2\pi \le x \le 0\}$

a) Find the period for each of graphs. (specify by colors.

b) Draw a conclusion for the relation between the period and the B. Do you agree with this formula? Justify your answer.

P= $\frac{2\pi}{|B|}$

Submit and Explain

Figure 7: Exploring the period of sine and cosine functions

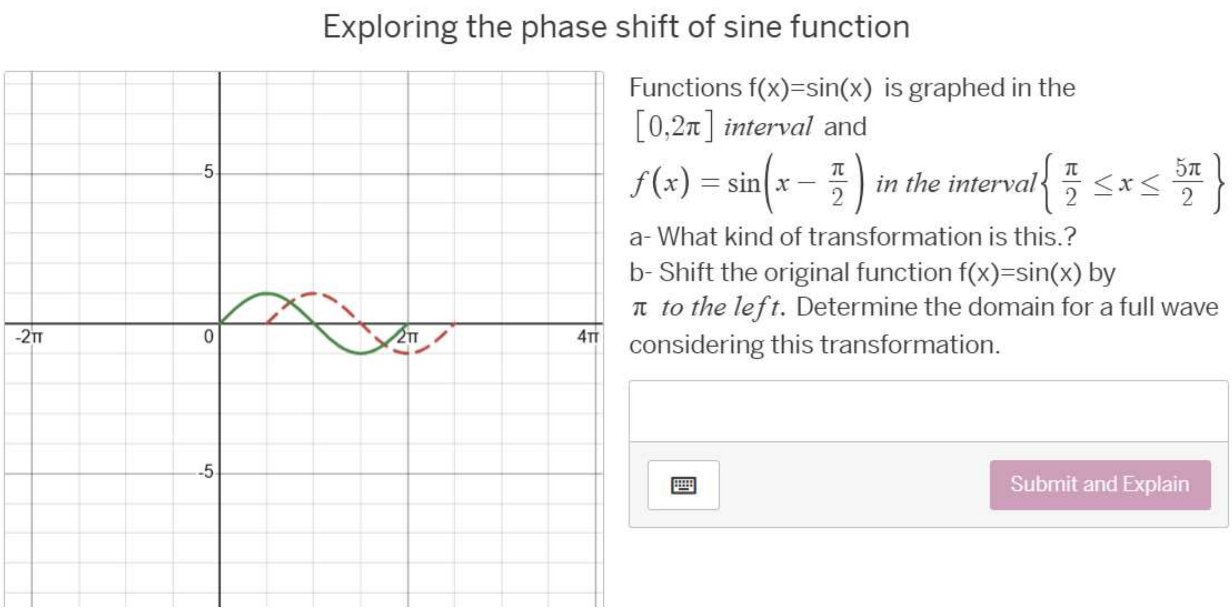


Figure 8: Exploring phase shifts of sine functions

Study Participants

The participants in this study were students enrolled in the Algebra and Trigonometry course sections MAT 115.C28 and MAT 115.C58 during Fall 2022, and sections MAT 115.C42 and MAT 115.C55 during Spring 2023. Students registered for these sections based on their own preferences.

	Learning Trigonometry using Desmos	Learning Trigonometry without Desmos
Fall 2022	MAT 115.C28	MAT 115.C58
Spring 2023	MAT 115.C42	MAT 115.C55

Table 1: Sections of Algebra and Trigonometry Involved in the Study

Description

The study employs a quasi-experimental, pretest-pos-test design. Participants were not randomly assigned to conditions, as they enrolled in course sections of their own choosing. To establish baseline equivalence between the two selected groups (course sections), a pre-test was administered focusing on the study's key measure: student performance on trigonometric function questions, assessed through their test scores. The aim was to ensure the groups were as comparable as possible prior to instruction. The educational intervention involved integrating Desmos-based activities into instruction on trigonometric functions for the experimental group during Fall 2022 and Spring 2023. In contrast, the control groups received traditional instruction without the use of Desmos. The instructional content and instructor were consistent across all groups. Post-tests were administered at the conclusion of the trigonometric functions' unit. During Fall 2022 and Spring 2023, pre-test and post-test scores, along with scores on trigonometry questions from the final exams, were recorded for course sections that used Desmos and those that did not. Additionally, average group performance on trigonometric questions from the final exams was recorded and compared to help validate the post-test results.

RESULTS

For the purposes of the study, two sections of MAT 115 were compared in Fall 2022 and Spring 2023. In Fall 2022, pre-tests were administered to both groups before the trigonometric functions' unit.

Both groups, MAT 115-C28 and MAT 115-C58 had the same average pre-test score of 55, providing a consistent baseline for analysis. The section, MAT 115-C28, which incorporated Desmos into their lessons on trigonometric functions, achieved an average post-test score of 83, reflecting a 28-point increase. In contrast, the second section, MAT 115-C58, which did not use Desmos, saw a more modest improvement. Their post-test average rose to 70, resulting in a 15-point gain. Figure 9 below summarizes these findings.

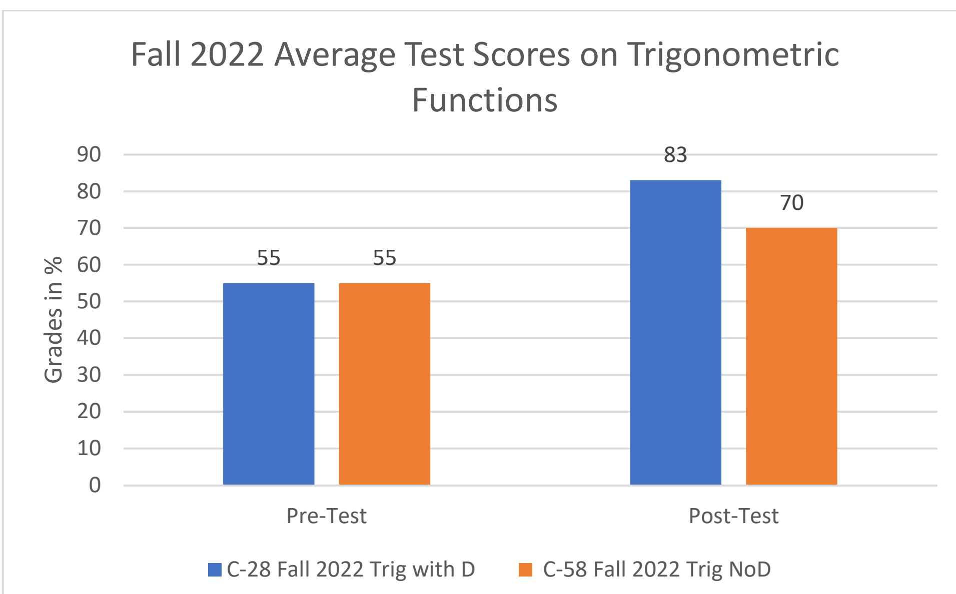


Figure 9: Comparison of average pre- and post-test scores in Fall 2022

In Spring 2023, another comparison was conducted to evaluate the effectiveness of Desmos in supporting student learning in trigonometry. Two other sections of MAT 115 were compared—one that integrated Desmos into instruction and one that did not.

Section MAT 115-C42, which used Desmos, began the term with an average pre-test score of 39. By the end of the course, students in this group had achieved a post-test average of 88, reflecting a 49-point improvement. In contrast, section MAT 115-C55 did not use Desmos in their instruction. Students in this group had a similar starting point, with an average pre-test score of 38. Their post-test average rose to 78, showing a 40-point gain. Figure 10 below shows these findings.

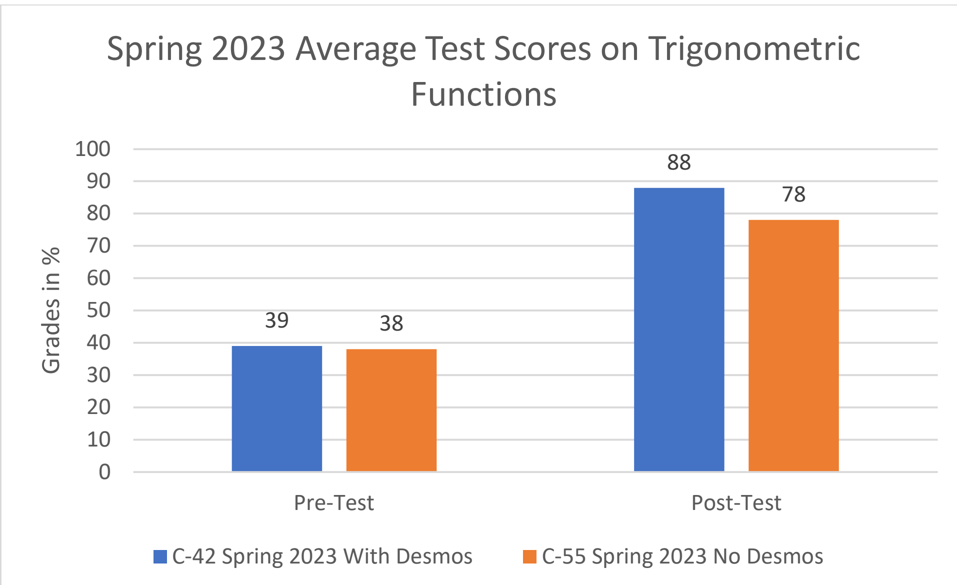


Figure 10: Comparison of average pre- and post-test scores in Spring 2023

Finally, in both semesters the trigonometry section of the final exam was used to confirm the post-test results. In Fall 2022, section MAT 115-C28, which incorporated Desmos, achieved an average score of 82 on the trigonometry portion of the final exam. In contrast, section MAT 115-C58, which did not use Desmos, had a significantly lower average of 60 on the same portion of the exam.

In Fall 2022, section MAT 115-C28, which incorporated Desmos, achieved an average score of 82 on the trigonometry portion of the final exam. In contrast, section MAT 115-C58, which did not use Desmos, had a significantly lower average of 60 on the same portion of the exam. In Spring 2023, section MAT 115-C42, which used Desmos, achieved an average score of 71 on the trigonometry portion of the final exam. In contrast, which did not use Desmos, MAT 115-C55 had a slightly lower average of 69 on the same portion of the exam.

Semester	Course	Pre-Test Average %	Post-Test Average %	Final Exam Trig Average % (score/total)
Fall 2022	Trigonometry with Desmos (MAT 115-C28)	55	83	82
	Trigonometry without Desmos (MAT 115-C58)	55	70	60
Spring 2023	Trigonometry with Desmos (MAT 115-C42)	39	88	71
	Trigonometry without Desmos (MAT 115-C55)	38	78	69

Table 2: Summary of pre-test, post-test and final exam trigonometry section average scores

Across both semesters, the data consistently shows that students who used Desmos experienced greater gains between pre- and post-tests and generally performed better on the trigonometry portion of the final exam. These results suggest that integrating Desmos into trigonometry instruction not only enhances immediate learning but also contributes to better long-term retention and application of trigonometric concepts.

DISCUSSION

One of the key advantages of using Desmos in the classroom is that it enables instructors to closely monitor each student's progress through features like the dashboard. Tools such as the 'overlay' and 'summary' options allow teachers to quickly identify misunderstandings, pinpoint errors, and provide timely feedback—greatly enhancing the learning experience.

Findings from the Fall 2022 and Spring 2023 semesters consistently demonstrated the positive impact of Desmos activities on student performance, particularly in relation to trigonometric functions. The integration of Desmos not only improved student understanding of trigonometric concepts but also fostered greater engagement, collaboration, and an exploratory approach to learning.

It is important to emphasize that using Desmos does not replace traditional methods such as graphing by hand with paper and pencil. Students are still encouraged to practice manual graphing to build foundational skills. However, Desmos enhances the learning process by allowing students to explore mathematical ideas more efficiently, minimizing repetitive calculations that can hinder progress. For instance, while creating tables or graphing functions manually can be time-consuming, Desmos simplifies these tasks. After sketching a function by hand, students can use Desmos to quickly investigate transformations. Additionally, the platform includes a sketchpad feature that simulates the feel of working on paper, helping to integrate technology into traditional learning practices in a seamless way.

Despite these advantages, several challenges emerged during the study. A lack of prior knowledge among some students led to gaps in understanding and slowed their progress. Although Desmos supports self-paced learning, ensuring the entire class moves forward cohesively requires careful planning and classroom management. Allowing students extra time outside of class to complete assignments can help, but this approach is less effective if students do not complete the work independently.

Assessment and feedback posed another set of challenges. Evaluating tasks—especially those involving student explanations, interpretations, and open-ended responses—can be time-consuming and demand significant effort. One strategy to address this is grouping common issues and discussing them during class, which can make the feedback process more efficient and impactful.

CONCLUSION

Research conducted over two semesters indicates that incorporating Desmos activities significantly enhanced student performance, particularly in understanding trigonometric functions. The data suggests that early integration of Desmos contributes to improved overall course outcomes and deeper engagement with mathematical concepts. These findings highlight Desmos as an effective tool for enhancing mathematics education. Introducing technology-driven activities early in the curriculum provides substantial educational benefits, including increased student engagement and achievement. Interactive features, such as manipulating constants and using sliders, proved far more engaging than traditional approaches. While some challenges remain, such as maintaining consistent pacing and providing detailed feedback, overall participation and engagement improved noticeably.

To maximize student success, it is recommended that Desmos activities be implemented at the beginning of the semester across various mathematical topics. Future research could investigate the long-term effects of such interventions and their effectiveness in different areas of mathematics and educational contexts. In conclusion, integrating Desmos into mathematics instruction has a clear, positive impact on student learning and performance, especially when introduced early. Despite logistical challenges, the benefits to student understanding, engagement, and retention are compelling.

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APPENDIX

Below are the slides of one Desmos activity designed by the author and used in the study.

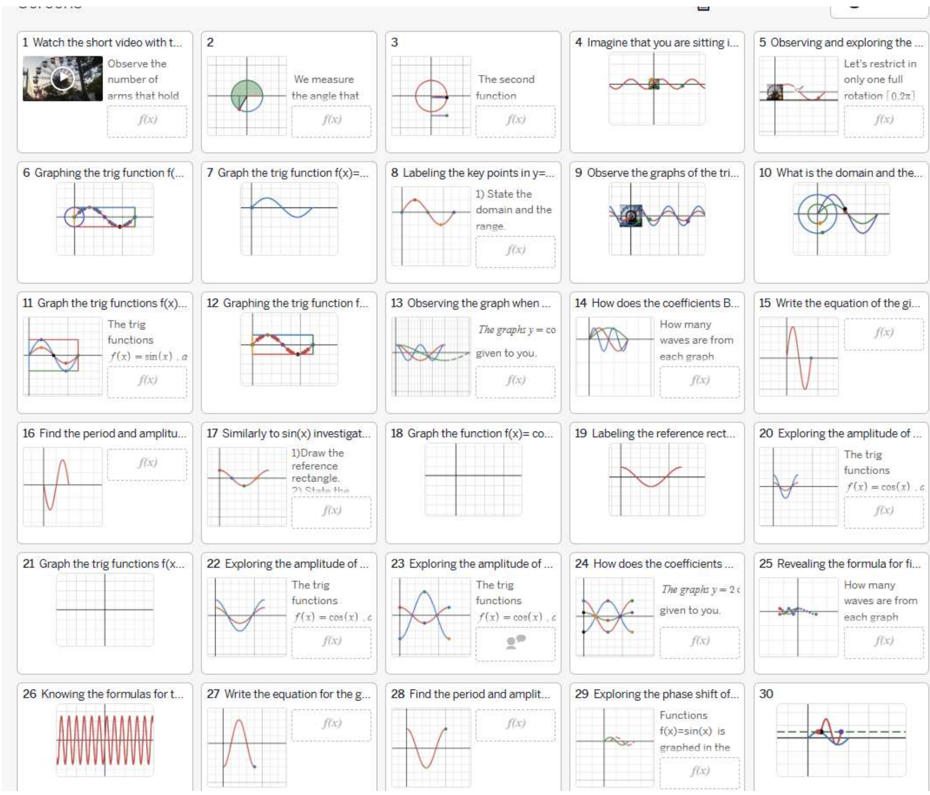
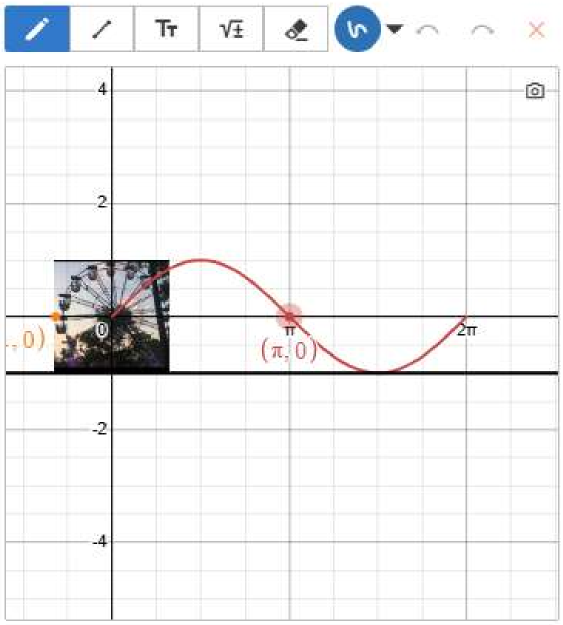


Figure A1. A Desmos activity with multiple slides

Several anonymized samples of students' responses to this activity in Desmos were selected and are shown below. These responses can be projected for class discussion. Displaying these responses allows students to compare different approaches, identify common mistakes, and collaboratively discuss corrections. Facilitating these discussions encourages peer learning, promotes deeper understanding of problem-solving strategies, and helps students refine their own thinking. Visualizing correct solutions alongside common errors enhances conceptual understanding and supports students in drawing meaningful conclusions from their work.

Observing and exploring the connections between the real life application and graphing



Let's restrict in only one full rotation $[0,2\pi]$.

a) What is the highest point that a person seating in on of the seats can reach. (ignore the height above the ground of the lowest point).

b)How high from the ground is it if the radius is 100 m?

c) What is the angle that corresponds to three quarters height from the ground? (consider the standard position)

d)Calculate the three quarters of the height from the ground in two different ways. You can use the sketch pad in the blank parts near the graph to sketch to support your solution.

e)Do the answers match?

Answer each question labeled from a to e

$100m$, $200m$, $\frac{\pi}{6}$ or $\frac{5\pi}{6}$,

Edit my response

Explain your thinking.

a) the highest point a person can reach is 100m above the center

b)the center of the Ferris wheel is at height 100m the same as the radius so the highest point is center height + radius = 100+100 =200m

c)H: 0.75 x 200 = 150m

y= r sin(O)+r

150=100sin(o)+100

sin(O)=150-100/100

sin(O)=0.5

Figure A2. A student's response: Exploring connecting between a Ferris Wheel rotation and a trigonometric function graph

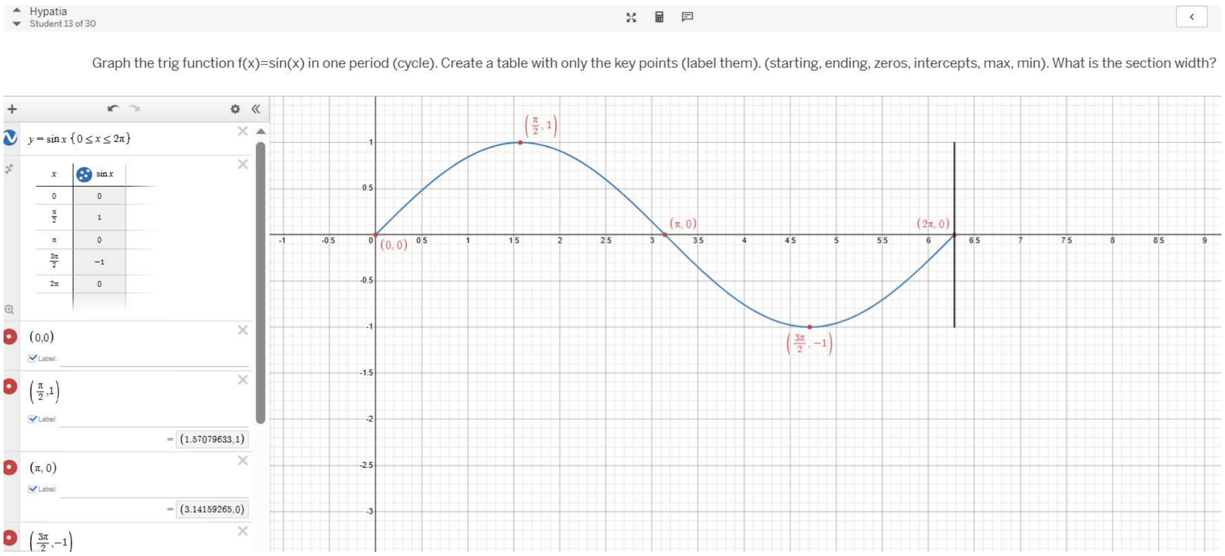


Figure A3. A student's response: Creating a table with key points of the graph

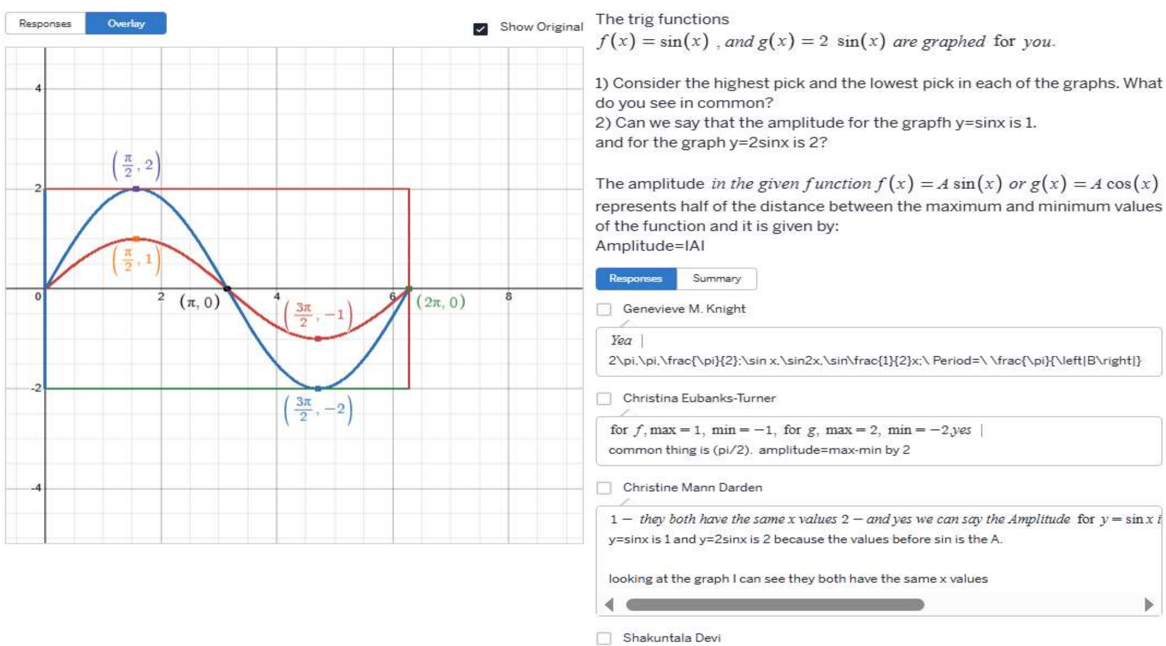


Figure A4. A student's response: Comparing graphs of two sine functions

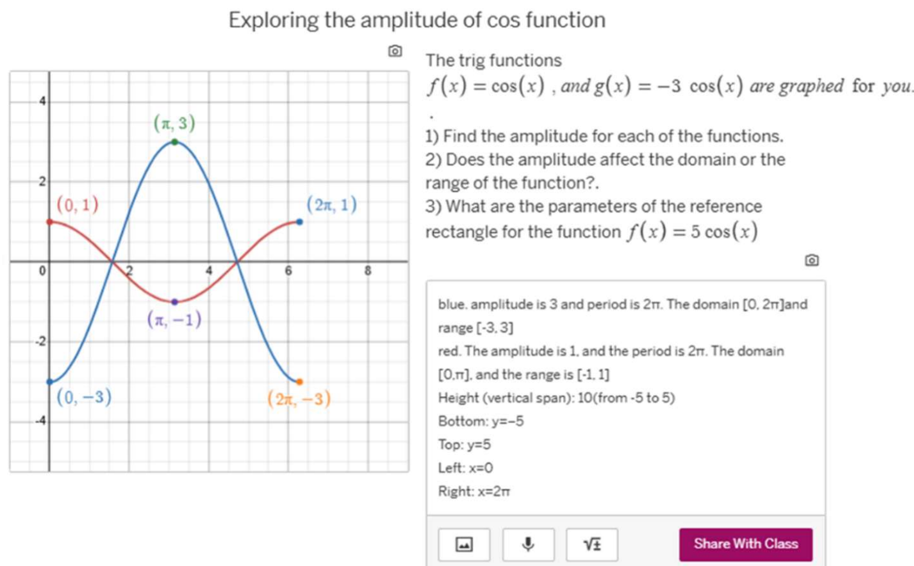


Figure A5: A student's response: Exploring amplitude of cosine functions

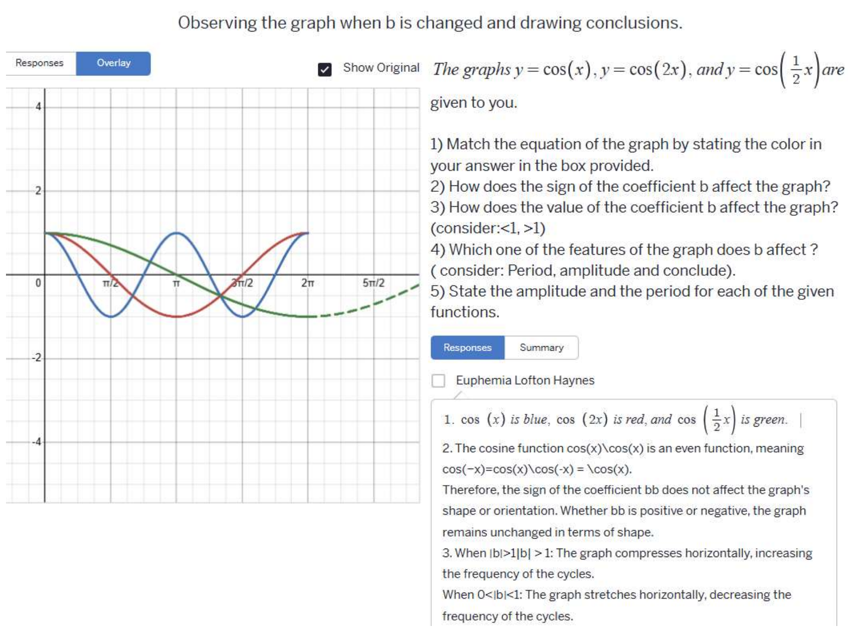


Figure A6: A student's response: Exploring amplitude and period of cosine functions

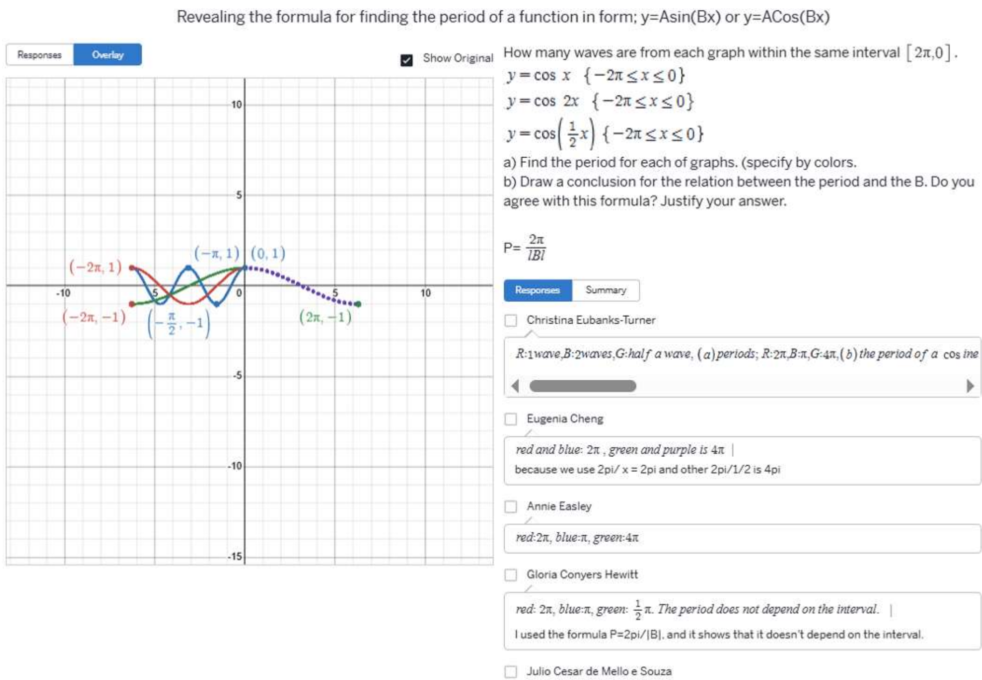


Figure A7. A student's response: Exploring period of cosine functions

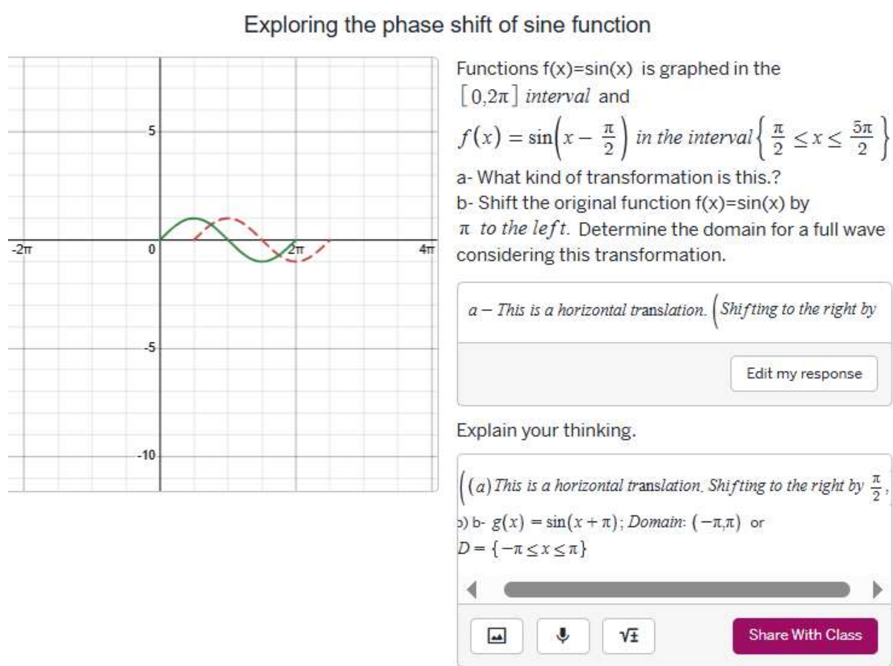


Figure A8. A student's response: Exploring phase shift of sine function

About the Author

Lucie Mingla specializes in math education, applied mathematics, digital technology, and logic, with degrees from the University of Tirana and Mercy University in New York. She actively presents at national and international conferences, including CUNY, AMATYC, MAA, ICTCM (Pearson) and the Global Education Conferences, emphasizing digital tools and global learning through COIL. Her publications and grant work focus on innovative, sustainable, and inclusive teaching, including Open Educational Resources and interdisciplinary math applications. At LaGuardia, she leads the "Math is Everywhere" initiative and contributes nationally through AMATYC IMPACT Live and standards revision efforts.