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."

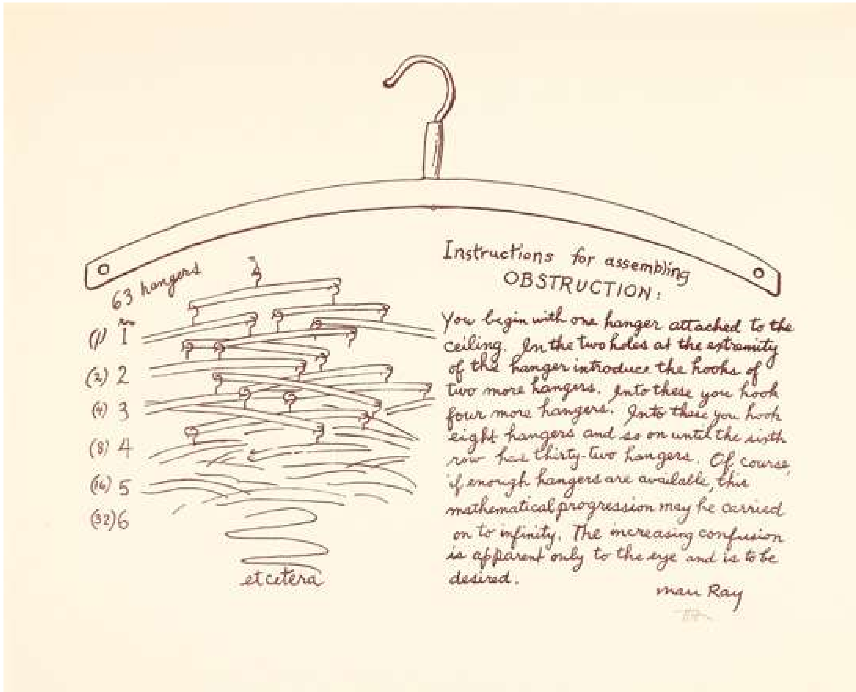

Figure 2: Instructions for assembling "Obstruction," by Man Ray (Source: http://radicalart.info/kinetics/Turn/MobilesAMain/index.html)

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.

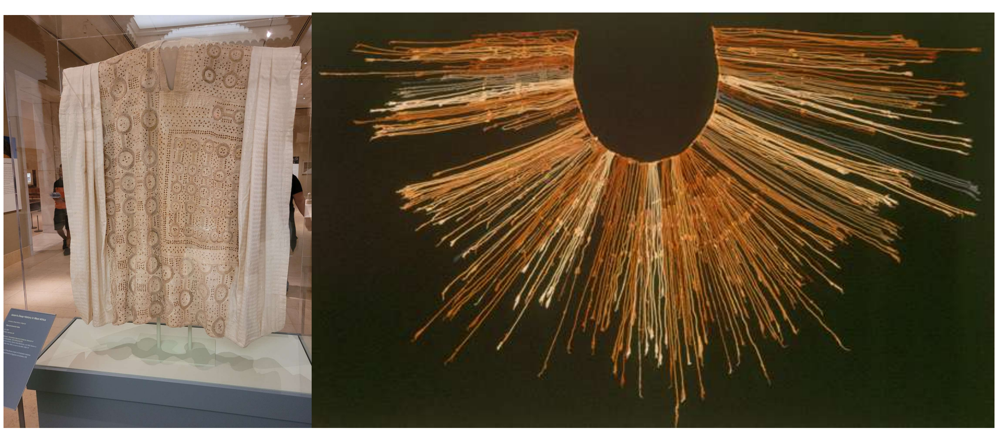

Figure 3: Left: Riga (photo taken by Renee Bell), a ceremonial robe from Nigeria. Right: Quipu, Incan recording device (Source: https://en.wikipedia.org/wiki/Quipu)

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.

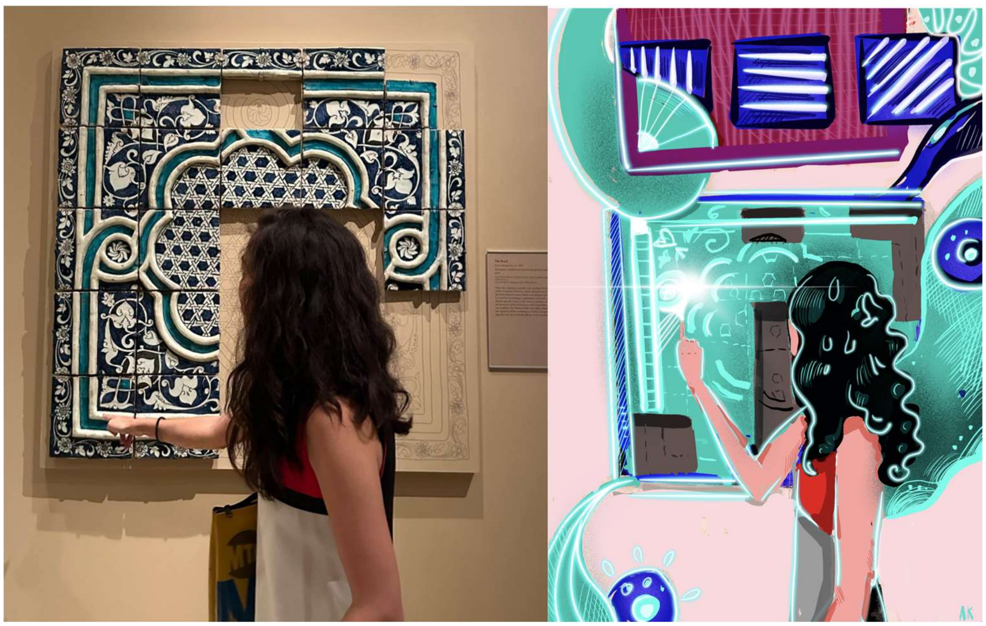

Figure 4: Left: Image of the tile panel at the Met museum (photo by Renee Bell). Right: Digital art by student Albina Krasykova.

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.

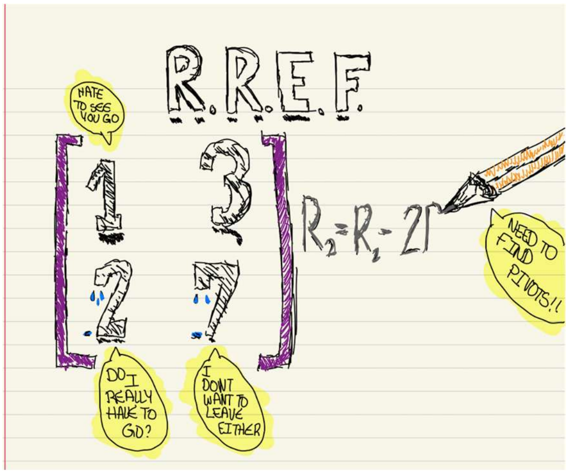

Figure 6: Depiction of of Gaussian elimination by student Jasmine Demoya.

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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