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Synesthesia: 3.1415... Orange.WhitePeriwinkleWhiteBlue...

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Synopsis

In this paper we address the questions: What is synesthesia? What support(s) can teachers provide for students who have synesthesia? Nicole, a future mathematics teacher who possesses this synesthesia "superpower", describes how it has impacted her learning. We collected data for this case study through an audio-recorded and transcribed interview, as well as from subsequent email correspondence between the three authors. We asked Nicole three kinds of questions: questions she is frequently asked, questions she would like to be asked, and questions teachers (like Shelly and Beth) might ask. Results indicate that synesthesia may have helped Nicole learn English as a second language as well as memorize certain mathematical formulas and procedures. Questions arose that, if answered, may influence the learning of not only other synesthetes in the mathematics classroom but also their classmates.

Keywords: synesthesia, grapheme-color synesthesia, sensory experiences, mathematics, teaching and learning

1. Synesthesia: 3.1415... Orange.WhitePeriwinkleWhiteBlue...

Imagine that when you see the numeral three (3) you are convinced it is orange. This is how Nicole sees a 3. As mathematics educators, Shelly and Beth were curious about the story that Nicole, a student in one of Beth's mathematics courses and a preservice mathematics teacher, recounted about how she memorized the digits of pi:

> My former high school pre-calculus teacher gave my class the rare opportunity to earn extra credit on an assignment. We were set to take a test on Friday, March 13$^{\text{th}}$—the day before Pi Day. In previous years, my teacher challenged students to memorize 100 digits of pi to earn extra credit on any assignment due on or near that date, but no one had taken advantage of the opportunity. Because the year was 2015 (making March 14$^{\text{th}}$ Super Pi Day) my teacher allowed students to be exempt from taking the test if they could memorize 100 digits of pi by Friday. The night before I had to take the test, I made rows of ten numerals on a Word document and then on my iPad, I created a 10×10 grid to better illustrate the colors that I was seeing. After doing that, I practiced memorizing them in chunks. Each of these ten rows created a distinct color palette which I studied—I paid closer attention to the colors of the numbers than the numbers themselves because a spectrum of colors is easier for me to visualize and inherently represent the numbers I need to recite. [See Figure 1.]
>
> Once I could recite a row with ease, I would memorize the next row. After memorizing several rows together, I began to unconsciously chunk the digits in a way that *visually made more sense to me* rather than thinking of them in groups of ten. [For example, "58979" and "323846" have a sandwiching of digits/colors at the beginning or end. "693993" and "8998628" have duplicating digits that are sandwiched between two of the same digit.] Within half an hour, I had managed to recite all 100 digits from memory by relying on the color palettes that represented each chunk of numbers. I was my teacher's first student to successfully recite 100 digits of pi in class as we celebrated Super Pi Day. Ironically, I ended up taking the test anyway despite having done the work to be exempt from it. (Email correspondence, July 6, 2020)

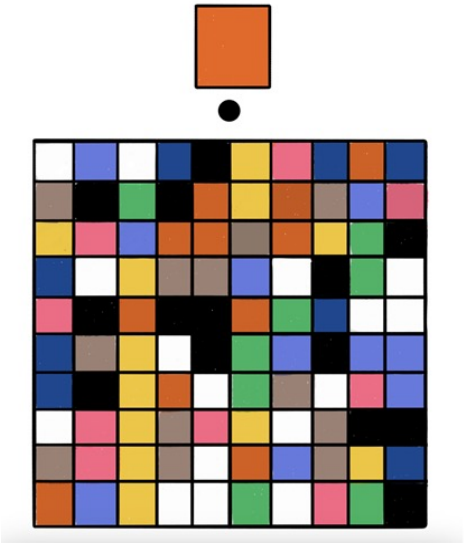

Figure 1: Nicole's grid of the numerals of pi..

When asked about this story during an interview (February 12, 2020), Nicole said:

> Yeah. It's just memorization. Even with pi. I mean I learned that [memorized the first 100 digits] in twenty minutes just by drawing out that little 10×10 grid and filling in the colors. I could just look over it, over and over again, and just kind of drill all that picture into my head and then I had it memorized. And it's been very helpful. [Laughs] For other people that may take, I don't know, how long would it take?

Beth replied:

> So, you're associating those numbers with their colors and then you know you kind of mention you have that "palette in your head," right? Even if I took someone's phone number, seven digits, and associated a color with them, and tried to put that palette in my head I wouldn't remember the palette.

As someone who does not have the "superpower," that seemed a reasonable response. Yet Nicole has that palette in her head.

2. Curiosity

Because of Nicole's story, Shelly and Beth became curious about synesthesia and sought Internal Review Board approval to interview Nicole; our research was deemed exempt. We wanted to answer two research questions: what is synesthesia? what supports can be provided for Nicole and for other students who have synesthesia? Together, the three of us created an interview protocol (see below) with the following categories of questions: questions Nicole is frequently asked, questions Nicole would like to be asked, and questions teachers might ask. We chose these questions because we felt they would help us address our research questions.

Synesthesia Interview Protocol

Questions Nicole is frequently asked

- What happens if a word/number is colored a different color than the one you perceive it to be?
- Do letters/numbers stay the same color?
- How long have you had synesthesia?
- In what ways is synesthesia distracting (e.g., seeing these colors all of the time)?
- In what ways is synesthesia beneficial? [Shelly added this question.]
- Does everyone see the same colors as you?

Questions Nicole would like to be asked

- How does your synesthesia help you with exams?
- How does it help make it easier to remember mathematical formulas? Give an example [Shelly added this follow-up question.]
- If every one-digit number has its own color, what color is an n-digit number?
- Is your synesthesia spatial? If so, how? [Shelly added this follow-up question.]
- What are some common misconceptions that people have about your synesthesia?
- Do you think synesthesia is learned or innate? Why? [Shelly added this follow-up question.]
- Can you turn synesthesia off? If so, when? [Shelly added this follow-up question.]

SYNESTHESIA INTERVIEW PROTOCOL - CONTINUED

Questions Teacher (like Beth and Shelly) Might Ask

- Tell stories about how you knew you had this super power. [Start with this question.]
- What recommendations do you have for mathematics teachers who have students with this super power?

3. Delving into the Literature

Interestingly, in our search for literature, we encountered a somewhat similar story told by Daniel Tammet [13]. On Pi Day, March 14, 2004, Tammet recited the first 22,514 digits of π in five hours and nine minutes and said:

> When I look at a sequence of numbers, my head begins to fill with colors, shapes, and textures that knit together spontaneously to form a visual landscape ... I simply retrace the different shapes and textures in my head and read the numbers out from them. (Tammet as cited by [13], page 110)

Tammet described the 762^{nd} through 767^{th} decimal places of π, 999999 (the Feynman point, named after the Noble prize-winning physicist Richard Feynman), as a "deep thick rim of dark blue light" [10]. As noted in his quote above, Tammet experienced space (deep), texture (thick rim), and color (dark blue light). According to Ward, Feynman was also a synesthete who saw numbers in colors [13].

3.1. What is Synesthesia?

As per the *Internet Encyclopedia of Philosophy* [5], the word "synesthesia" or "synaesthesia," has its origin in the Greek roots, *syn*, meaning union, and *aesthesis*, meaning sensation: a union of the senses. People with synesthesia are often called synesthetes. A synesthete might hear a song and smell chocolate chip cookies fresh from the oven (hearing linked with smell). Other synesthetes, such as Nicole, might envision letters of the alphabet and/or numerals as colors. In fact, we learned that Nicole's synesthesia has a specific name: grapheme-color synesthesia [15].

Grapheme-color synesthesia is one of the most studied types. Curiously, it is extremely unlikely that any two people will report the same colors for all letters of the alphabet and numerals; however, studies of large numbers of

synesthetes found that there were some commonalities across letters of the alphabet and colors ("A" is likely to be red) (e.g. [2] and [4]). Witthoff and Winawer [16] documented a case study of a synesthete who associated letters of the alphabet with the colors of alphabet refrigerator magnets, and some synesthetes seem to use "meaning-based rules" such as the letter b being blue and the letter o being orange [15]. However, Nicole did not report using colors of refrigerator magnets or meaning-based rules for different numerals.

Simner and colleagues [9] reported that one in ninety people experience grapheme-color synesthesia and one in twenty-three people experience some type of synesthesia. Experiencing color for days of the week was the most common type.

3.2. Synesthetes' awareness of their "superpower"

Synesthetes often report that they were typically unaware that their sensory experiences were unusual until they realized others did not have the same sensory experiences; many vividly recall when they first noticed or learned that their sensory experiences were not typical [4].

When asked to recall stories about when she initially realized she had synesthesia, Nicole responded:

> Well, for as long as I can remember I've had it but I didn't know that it was something that most people didn't have until a little bit later. Until like when I was in Kindergarten [stops]. Well, I should probably say that English is not my first language so when I was learning English and I was in Kindergarten, still not entirely fluent with English, it was a really easy way for me to remember words by remembering their colors. So, I would remember that the word "cats" [stops]. Cat is orange or I would think of orange cats every time I saw that word. So, I knew that when I had to spell it, because it's orange [pause], I knew it had to start with a "c" and not a "k" even though it's got that "k" sound to it. And the "a" in cat is also like a scarlet-y kind of color so that's how I would remember, um, words [and how to spell them] when I was little. And that was [the same] with every word. So "table" was black, "telephone" was black, "chair" was orange but not quite as orange as "cat." Etcetera. "Pajamas" were purple. And I had to have purple pajamas. [Laughs]

Nicole's first language was Dutch, so Beth followed up by asking if synesthesia helped Nicole learn English and she said:

> Oh, definitely. Because I was fluent within like no time. I mean kids learn languages easily anyway, but synesthesia just helped me remember much easier, especially when I had to write it out. Because I had to remember how to spell words, every distinct letter had its own color and I could remember words better that way by remembering, "Oh yeah, 'cat' was orange-ish so it needed these letters in it."

Asked to recall other stories about when she knew she saw letters and numbers as colors, Nicole noted:

> I think one of the first clues was when I was in seventh grade. I was in marching band. And at one of our competitions another band member was talking about the energy drink Monster™ and she said that the monster was green because that's what the color of the brand Monster™ was and I was like, "What?" [Emphasis]. It didn't make sense to me why she would say monster's green when to me it was so clearly blue. And then she was like, "What are you talking about?" Then she showed me the drink that she had in her hand and that's when it like made sense to me. Oh, she's talking about the drink. But she thought it was weird that I thought it was blue so that's when I started questioning. Does nobody else see these colors or words together the way that I do? So that was my first clue. But I think I finally learned what that word was—"synesthesia"—and that I had it and that other people typically don't when I was in a psychology class in high school. It was [Pause] I want to say my junior year of high school and that word came up in a conversation or a PowerPoint™ slide and I was like, "wait a minute, that sounds a little too familiar." So then I went online and I looked into it a little bit more and, "Yep, that's me." So that's when I finally discovered that that's what I had.

Nicole's description in the interview and subsequent conversations and email correspondence corroborated the unconscious nature of her experience. A synesthete might see a numeral printed in black but also experience "greenness" which is both automatic and involuntary [2, page 63]. The interview

and subsequent email correspondence also indicated that Nicole thought everyone had the same sensory experiences that she had until she was in seventh grade.

3.3. Brain Connections

According to Weiss and Fink, brain researchers found that grapheme-color synesthetes have more grey matter in their brains [14]. Nicole, who was familiar with the term grey matter, said, "It is generally located in the outermost layer of the brain, the cerebral cortex. Memory is 'stored' in the hippocampus which is fundamentally different from the cerebral cortex. I'd presume that the amount of grey matter can influence one's processing of information, but not their retention of it. I wonder, when they say that synesthetes have more grey matter, if they mean within the entire brain, or if only in particular lobes, each of which are responsible for processing different types of information" (Comment, January 7, 2022).

Only about 10% of synesthetes experience eidetic images or "photographic memory," but some researchers note that synesthesia helps with memory, as it does for Nicole [7, page 53]. Cytowic and Eagleman [2] described "the most plausible hypothesis for why synesthetic brains differ from non-synesthetic ones":

> Synesthesia reflects an *increased degree of cross talk* between normally separated brain areas and the networks of which they are a part. (page 205, italics added for emphasis)

Perhaps, as Ward argued, sensory experiences are a product of activity in specialized regions of the brain. Yet "our senses are not as separate as we often assume" [13, page 41], and sensory experiences can be enhanced or reduced by either attending to or ignoring them. For example, our perception of food is typically multisensory because we notice taste, smell, color, texture, temperature, and even sound [13]. Think about eating an oatmeal raisin cookie straight from the oven. Imagine the taste of the sweet raisins, smell the cinnamon, feel the texture of the nuts on your tongue, savor the warmness, and hear the slight crunch. This is a multi-sensory experience. Interestingly, we sometimes use metaphors to connect distinct sensory experiences with each other with expressions such as "loud tie," "cool jazz," "sharp cheese," or "sour note" [7]. Are they truly distinct?

3.4. Famous Synthetes

One of history's most famous impressionist artists, Vincent Van Gogh, lived with synesthesia in a time when it was considered a "cycloid psychosis" rather than a superpower or gift [12]. Although some attribute Edgar Degas' broad, less-precise, brushstrokes to his deteriorating eyesight as he aged, others suggest that due to his failing eyesight he focused more on the emotion of colors in his paintings (https://listal.com/list/famous-people-with-synesthesia). Another artist, Vasily Kandinsky wrote, "I let myself go. I had little thought for houses and trees, drawing colored lines and blobs on the canvas with my palette knife, making them sing just as powerfully as I knew how... I could hear the hiss of the colors as they mingled" (as cited in [8, pages 32-33]). The Dutch artist Mondrian attempted to "visualize rhythm" in his grid artwork designs [11, page 58]. For example, in his *Composition with Gray Lines* (1918), a rhombus with grids of squares with diagonal lines to form triangles within the squares was one of his initial efforts to show rhythm or movement. He used line segments with different thicknesses and with gray tones to help create this effect. Later in his career, he painted his *Boogie-Woogie* series in response to music he heard in New York jazz clubs.

Musicians such as Pharrell Williams link sounds with colors and, interestingly, "chords would be blends of different shades, and harmonies would likely involve the blending of compatible colors" [3]. Duke Ellington saw both colors and textures in notes and described the blend when fellow musicians were playing their instruments [3]: "If Harry Carney is playing, D is dark blue burlap. If Johnny Hodges is playing, G becomes light blue satin."

Nicole noted that, "It might be notable to indicate that the artists listed here, had a different type of synesthesia (than mine). Sound-color synesthesia is called 'chromesthesia.' I can't recall where I saw it before, but it's likely that anyone who has one type of synesthesia has multiple types. For me, grapheme-color is certainly the most dominant, chromesthesia is not as vivid, but still present, and so is spatial-sequence synesthesia" (Comment, January 7, 2022).

3.5. Painting music

As she noted above, Nicole sees color and movement in music. Before the interview, Beth asked Nicole to paint a picture while listening to the song "Fearless" by Pink Floyd. Nicole described how she created the painting in Figure 2:

> I had to listen to that, uh, song that you had sent me and that's kind of an essence kind of thing. Like I want to go back to that word, *essence*, because even though every lyric in that song had its own distinct color, that would have been a mess of a picture if I had to draw that out. Because every single word is different and like in the definitions, when I'm memorizing definitions, I'm not remembering every single word in there. I just need the key words to remember that palette. So, with that song that you sent me I didn't need every single word in there. I just focused on the title, *Fearless*. So, that contributed a whole lot to the song because that's what it's called. That gave me a big *essence* of what that song was [about]. Then through listening to it a few times I kind of got more of its *essence* and then could kind of draw, kind of like a cloud, I suppose.

Figure 2: Nicole's painting of "Fearless".

Beth responded:

> However, with that painting it was more than a cloud, right? . . . that painting had, um, shade to it. It wasn't just clouds of color. There was movement in that painting. And there were, uh, distinguishing parts. I don't know how to talk about this but there were, um, different components to the painting that were not just clouds of color so to speak.

Nicole referred to a segment of the Walt Disney production *Fantasia* to explain. [Interestingly, "*Fantasia* is built on the idea of sound-to-sight correspondences, and many synesthetes say it is a reasonable illustration of what it is like to see sound" [2, page 90].]:

> I want to go back to *Fantasia* ... So if you remember it's like with the, I don't know, with what do you call it? Notes, beats, I don't know. Strikes or whatever when the violins are making a new sound. It's kind of [stops]. I mean if it's a lower pitch then whatever blob of whatever shape of color was it would be lower and then higher notes when higher. But because we're moving forward, I'm always thinking going this way [left to right motion] cause it's almost like a graph in that way ... It's really bizarre to try to explain. *Fantasia* really does a better job if you watch that first nine minutes ... Because you can actually see it happening. Versus your painting is a still picture trying to capture all of that happening.

Beth attempted to get Nicole to clarify the process she used when she painted her interpretation of "Fearless":

> So, when you painted the painting or when you [stops]. When you were listening to the song, here's what I'm imagining. Okay. Right? I don't know ... Clearly ... But I'm imagining it was sort of like for you a combination between what you painted and what *Fantasia* looked like.

Nicole illuminated the difference between her motionless painting of "Fearless" and the motion in the segment from *Fantasia*:

> Because, um, in that painting I obviously cannot do this note at this one point in time and then this one and this one moving forward because I couldn't do a motion picture, basically. So, I had to kind of do pauses, freeze-frames, and try to overlap and so you've got the gist of all of it. The best that I could at least.

Beth emphasized the felt motion:

> I recognize that [in the "Fearless"] painting you are showing motion. You are showing movement. I mean it's still, but, um, I mean it's a stationary thing but the way you painted it there's clearly movement.

In a recent issue of the *New Yorker*, the cover artist, Masha Titova, was asked to "orchestrate a variety of sounds" in her design [6]. She noted that she harmonized the "various visual shapes as if they were part of a musical composition." *New Yorker* staffers who were musicians then met to record the aural elements of Titova's cover design. Visit the website www.newyorker.com/culture/cover-story/cover-story/2023-06-05 and you can *see* and *hear* the result of a synesthesia collaborative effort that includes both geometric shape and sound. What sound do you think a triangle makes? A circle? Would you use different instruments for these different shapes? Why? Or might the same instrument make totally different sounds?

4. Questions Math Instructors May Ask About Synesthesia

Perhaps teachers should know basic information about synesthesia as reported above. Shelly and Beth, both former mathematics teachers, knew nothing about synesthesia before meeting and talking with Nicole. However, Shelly recalled talking with a former student who indicated that even numbers were yellow and odd numbers were red. She thought it was a curious statement at the time. Did this former student have grapheme-color synesthesia?

As mathematics teacher educators, Shelly and Beth want to show students that they are important to us, and we want to provide support when students need them. After we heard Nicole's story, we were curious about synesthesia, so we searched for information about this "superpower." We also decided it was important to interview Nicole for her perspective on synesthesia because of our desire to learn from her. Perhaps we have had, or we currently have, other students with synesthesia. How can we best meet their needs?

van Campen pondered the notion that school systems essentially suppress the development of children's senses [11]. Because schools systems focus on teaching cognitive skills perhaps children "unlearn certain [sensory] skills in schools" and, "[Children's] senses contain more ways of knowing than the school system may suggest, or allow" [11, page 43]. Perhaps we are all born with synesthesia but we might suppress it as we go through school [1]. According to Nicole, ways that promoted her use of synesthesia in elementary school included "[a]lphabet charts in kindergarten (A = apple = red, B = bird = blue, C = cat = orange, D = dog, brown, E = egg = white, etc.) and classical music playing in the background in art class. Again, I think 'seeing'

colors helped in my development of the English language (even in learning larger vocabulary words after I was 'fluent')" (Comment, January 7, 2022).

According to Nicole, her teachers never suppressed her synesthesia skills mostly because she did not discuss or reveal how her use of color helped her learn language or memorize mathematical formulas. When asked about her recommendations for mathematics teachers who have students with synesthesia, Nicole said this was the question that she was "really scared of getting asked" and then elaborated:

> It's so difficult. If you have students with my kind of synesthesia I mean they could all be different. And you could have multiple students with the same type of synesthesia and then [the students] maybe [they] just see completely different things ... Um, the only thing that I can think of like was in maybe a K-12 school or something. If we ever had to do notes or we had to highlight some certain things. To have some colors available to write these words in. Because when I needed, I don't know, to take notes on the quadratic formula it probably would have helped me even more if I had like a blue marker to write "b," and then write it out that way [in blue]. See it's just so difficult. You're a mathematics teacher, what would you do to me?

Beth responded:

> Well, when you said that this thought came to my mind. I don't know if it's meaningful at all but just having colored pencils or pens available. You know, might prompt the student who has synesthesia to try to connect what they're learning to how they're picturing it and thinking about it as they're learning it and maybe make those tight connections like you do. Um, while they're learning it instead of when they go home or, you know, the next day or something like that.

Nicole replied:

> I've got markers and pens at home. I don't typically bring them with me. Maybe I should now that I'm thinking about it. But I mean people in classes, they'll switch colors for a different topic or they'll highlight certain words certain ways. So I don't know. Just having, how many colors would you need? I probably need

> just like eight or nine to be happy. I mean there's different shades but I can deal with the wrong shade of orange. It's close enough. So, if I could've written my notes out that way I probably really could have remembered it better. I don't know if that would work for the neurotypical people. [Laughs]

Nicole laughingly referred to people without synesthesia as "neurotypical" and then Beth described how she treated Nicole in class:

> And I had you in class. And I mean I don't remember when I learned about this. Um, but I know for a fact I never thought about it during class. I will be honest and say, um, that I never thought, 'I know this about Nicole. How can I use that to help her in any way?' I mean just to be honest I didn't have those thoughts. I had the thought of how can I help Nicole. Like I would, you know, other students. And to a certain degree you always sort of try to individualize things but I don't remember having the conscious thought about synesthesia.

Nicole did not find fault with the fact that Beth did not make special accommodations for her:

> It's almost an unfair question because I already have this advantage. Like I already could memorize this in no time. So, it's almost like I [stops]. Like I've already got this built-in mnemonic device. I'm already like [stops]. ... [However] maybe it would help students who do struggle. I don't know. Because I mean with math in particular I don't, I've never really had a hard time and I've remembered rules and formulas pretty well.

When Beth asked if synesthesia has helped Nicole be successful in mathematics, she responded:

> That's a good question. I don't know. It helps me like remember formulas. I've got the numbers but the numbers don't really matter cause I mean with any equation it's different numbers ... I don't want to say that it's really helped me any more than anything else has helped me in math. It just [stops]. I guess the only thing that it does is, man that's probably not even true, either [stops]. I started to say something that wasn't true. Because it helps me to like memorize things. So, in a way, I guess it does

> help me be more successful. But I don't think that its gave [sic] me more of an appreciation for math. I like math because of other reasons. But I think the synesthesia helps me get good at it. Or remember things quicker.

As most any mathematics educator would do, Beth challenged Nicole's notion of mathematics as memorization of formulas and rules with her germane comment: "There's a lot more to mathematics than the part of mathematics that you feel synesthesia gives you an advantage in." Recall that Nicole was a future mathematics teacher; yet, like other future mathematics teachers, she had not moved beyond the notion that memorization of formulas helps mathematicians solve problems. Memorization does help students do exercises of course, so maybe another challenge for educators with synesthetic students is to find ways to encourage them to engage with the other dimensions of mathematics even when their "superpowers" make certain things so much easier.

5. Synesthesia as a Bridge Between Mathematics and Art

In this case study, we learned that synesthesia may have helped Nicole learn English as a second language as well as memorize certain mathematical formulas and procedures. Questions from this case study arose that, if answered, may influence the learning of not only other synesthetes in the mathematics classroom, but also their classmates.

There is a blurred line between people without synesthesia (or, as Nicole would say, "neurotypical people") and people with synesthesia [11]. Do schools, in fact, focus on cognitive learning to the detriment of learning through our senses? How can we create learning experiences that enhance students' sensory experiences? What can teachers do to develop the synesthesia that may be present in all students? Clearly, Nicole believed her synesthesia helped her academically. She wondered, "synaptic pruning removes 'unnecessary' neural connections from the brain which happens most rapidly during childhood (thank you, EDU 300, a required education course). Could synesthesia be a 'use it or lose it' condition?"

Perhaps, as mathematics teachers and mathematics teacher educators, we should not forget the connections between mathematics and the arts. The arts can bring multiple senses together to enhance students' learning and

possibly tap into the synesthesia that may be within all of us. Anecdotally, we know that learning experiences that connect mathematics and art, music, dance and other subjects that move beyond cognitive ways of knowing bring out the best in some of our students. They shine when they can walk a number line, move to the beat of the drum, draw tessellating designs, or write mathematical haiku. Enhancing the synesthesia in all students might serve as a bridge between mathematics and the arts and deepen their understanding of both fields.

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