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Constructing Kites to Integrate Mathematics and Arts Concepts

Abstract

This article describes a tetrahedral kite activity that was implemented with grade 9 students (age 14-15). We detail how the three-part lesson provided opportunities to integrate mathematics and art concepts, with potential to also weave in science and engineering ideas. The first part primed students to consider tetrahedral kites, their cultural and historical significance, and the materials needed for constructing the kite. The second part had students create a prototype using nets of tissue paper decorated with mark making techniques. The third part had students create a tetrahedron kite containing cultural and geographical mark making techniques on the tissue paper sides before flying the kites at a community event. We conclude the article with recommendations to help other teachers integrate mathematics and visual arts topics through tetrahedral kites.

Keywords

3D shapes, arts and mathematics integration, surface area, tetrahedral kite

Constructing Kites to Integrate Mathematics and Arts Concepts

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Have you ever seen a tetrahedral kite, perhaps hanging above your head in a school library or classroom or even flying against the blue sky? From a teacher perspective, this kite (Figure 1) offers connections between many different topics: triangles, surface area, properties of 3D shapes, weight, lift, and use of color.

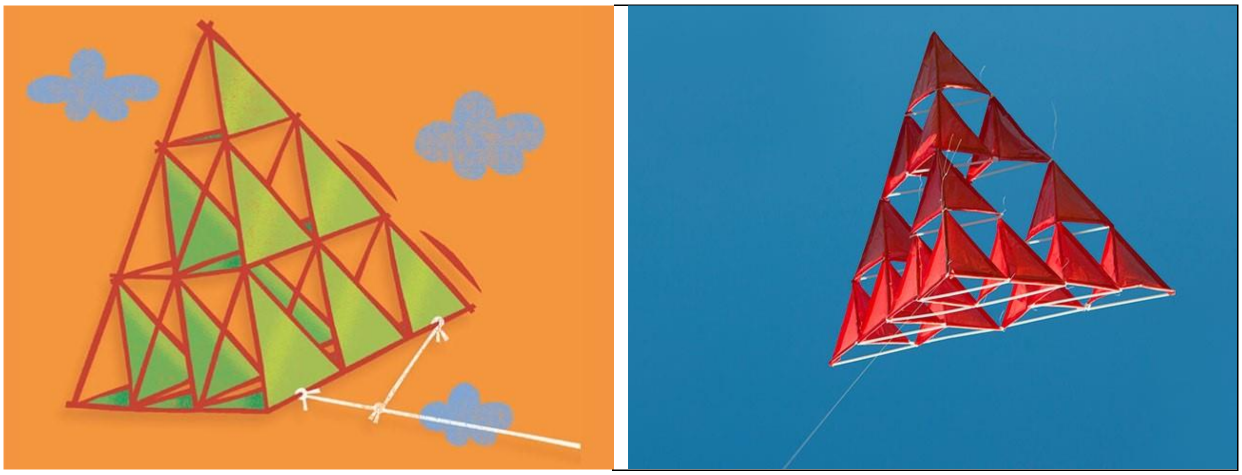

Figure 1: Images of tetrahedral kites.

In this article, we share how a high school art teacher implemented a three-part kite activity that allowed students to create a tetrahedral kite, apply mathematical ideas associated with building and flying the kite, and connect arts and mathematics concepts. We also present evidence this activity supported our high school mathematics and arts standards and offer advice for implementation the task in your school. While our context was within grade 9, the standards addressed and advice we offer is suitable to implementing this activity within grades 7-10.

Related Literature and Standards

Instructions on *how* to build a tetrahedral kite are plentiful in both print (King, 2004; Rushton, Ryan, & Swift, 2001) and video (a YouTube search for tetrahedral kite will produce several great resources). This article focuses on the ways this activity could - and should - be implemented in an arts classroom to support middle or high school art and mathematical concepts. Specific mathematical topics addressed by this kite activity range from creating 3D shapes from nets (Grade 6 Geometry standard 4), solving real-world and mathematical problems involving area, surface area, and volume (Grade 7 Geometry standard 6), and experimenting with theorems about area and volume of compare between similar shapes differing by a scale factor (High School Geometry Standard 1) as detailed in the Common Core State Standards Initiative (2011). Art standards (National Coalition for Core Arts Standards, 2014) addressed by the lesson include students developing skills with different materials, methods, and approaches in creating works of art or design (Grade 7 Visual Arts Standard 2.1), students explaining locations and cultures influence aesthetic choices and the resulting visual image (Grade 7 Visual Arts

Standard 7.1), and students reflection, revising, and refining "works of art or design considering relevant traditional and contemporary criteria as well as personal artistic vision" (High School Visual Art Advanced Standard 3.1, p. 2). The last two Visual Arts standards overlap nicely with central parts of the National Curriculum for Social Studies (Adler, Altoff, McGrew, & Tyson, 2012), particularly the themes of culture (theme 1) and people, places, and environment (theme 3)

In addition to content standards, this activity helps address literature calling for increased reasoning and subject integration at secondary schools. Students should be able to use mathematics to understand and operate in the physical world, connecting mathematics with real-world situations (NCTM, 2014). The need for students to learn integrated Science, Technology, Engineering, Arts, and Mathematics (STEAM) concepts is echoed in national calls for change (Brazell, 2013), with many schools shifting to promote this type of integration and cross-curricular knowledge within students. Increased emphasis on STEAM learning is reflected in literature featuring several published STEAM activities for elementary (Smith, King, & González, 2014), middle school (Lawrence & Yamagata, 2007) and high school students (George, 2014).

Activity Methods and Materials

This activity took place within a high school that prides itself on STEAM curricula woven throughout integrated classes. The three authors designed the activity to primarily focus on arts and mathematics concepts within the tetrahedral kite design, construction, and test flying, occasionally referencing basic physics concepts and engineering concepts. While we jointly assisted in implementation, Author 3 was the lead teacher in a freshman high school integrated art and social studies class containing 45 students and meeting daily for 90 minutes. This activity took 7 class periods, approximately two class periods for each of its three main parts. The first part exposed students to the cultural and historical perspectives of the kites, introduced the tetrahedral kite, and primed students to consider what and how much materials would be needed to construct a tetrahedral kite. The second part allowed students to practice creating a prototype with the materials they requested. The third part was creating the final product: each student created a single tetrahedron part of a kite containing mark making techniques on the tissue paper sides, conveying how physical features could represent the country's culture and geography. The colored tissue paper was used to construct a final kite from these tetrahedra that could actually fly. The needed materials included non-bending straws, tissue paper, and strong string that does not stretch; students actually calculate how much of these materials they need. Other materials that are likely already available in any arts classroom include: scissors, clear tape, and coloring utensils for each group of 3-4 students. We had students fly their kites at a local kite festival after this activity, so you may want to plan similarly if your area has such opportunities, or at least suitable weather to test the finished product.

Part 1: Kite Introduction

We began with announcing the local kite festival, about a month away. To get students excited about the event, we shared pictures of people flying kites from previous years and announced the students would be making their own kites to fly in the festival (Figure 1). We shared cultural and historical information on kites (Hang & Guo, 2010), including how kites differed across groups of people (Hosking, 2018), places (Parvez, 2018), and time periods. In this class discussion, we encouraged students to use mathematical vocabulary to describe the shapes and symmetry as well as artistic phrases to describe the colors, patterning, and line styles used in the various kite styles. We introduced the tetrahedral kite using both pictures and a physical example we had already constructed for students to brainstorm in small groups how the kite was created.

Appendix A contains a list of questions we used to help students consider the tetrahedral kite construction using relevant mathematics and visual arts vocabulary. These questions ask students to make sense of the words tetrahedral, tetrahedron, net, length, faces, surface area, and equilateral triangle. These questions address the mathematical topics: representing 3D figures using nets, estimation, computing the area of an equilateral triangle, computing surface area, and solving real world problems. To compute the equilateral triangle, students used rulers to manually determine the base and height of the equilateral triangle and could also use calculators. We found the 9th grade had forgotten how to compute the area of any triangle, despite having covered the topic the previous year. Thus, we reviewed and related computing the area of a right triangle and determining measurements of base and height of non-right triangles.

Engineering concepts incorporated in Part 1 questions include: estimating the materials each student needs. In particular, estimating the string length needed should include how much string is needed to tie a knot at each end, which relates to testing and modifying a process that leads to a more optimal use of materials (MS-ETS 1-4 Engineering Design Standards, Next Generation Science Standards Lead States, 2013). Science concepts are included by having students consider factors of mass and vertical position of the kite in the wind, conveying the idea that the force of gravity is being balanced by the lift generated by the wind pressure and drag on the kite (HS-PS2-1, HS-PS2-2, Next Generation Science Standards Lead States, 2013). One challenge question that can be asked after each student calculates the area of tissue paper needed to cover two sides of their tetrahedron is whether that net will fit on a single sheet of tissue paper. If there is time, you can even have groups estimate the cost of the materials for the group, using the internet to estimate the bulk pricing of items. We did not tell them we had already done this calculation, ordered and received the supplies.

Part 2: Prototype Construction

Part 2 asked students to create a first draft of the tetrahedral kite, which we called a prototype, and to decorate it with line art depicting the historical and cultural contexts of kites. To create the prototype, we first established specific recommendations of pulling the strings tight and double or triple knotting. Each student was expected to create two faces of the tetrahedra – essentially two attached equilateral triangles out of straws (Figure 2). We found some students had difficulty tying knots, and many students at first did not tie the knots tight. Students noticed that their prototype looked odd when the knots were loose. As students secured their tetrahedron to one another, the importance of having a tight knot was evident in keeping a compact tetrahedral shape. Since it is critical for the knots to be secure and tight if the kite is to fly optimally, we recommend emphasizing the importance of these qualities and encouraging students to help each other meet these requirements.

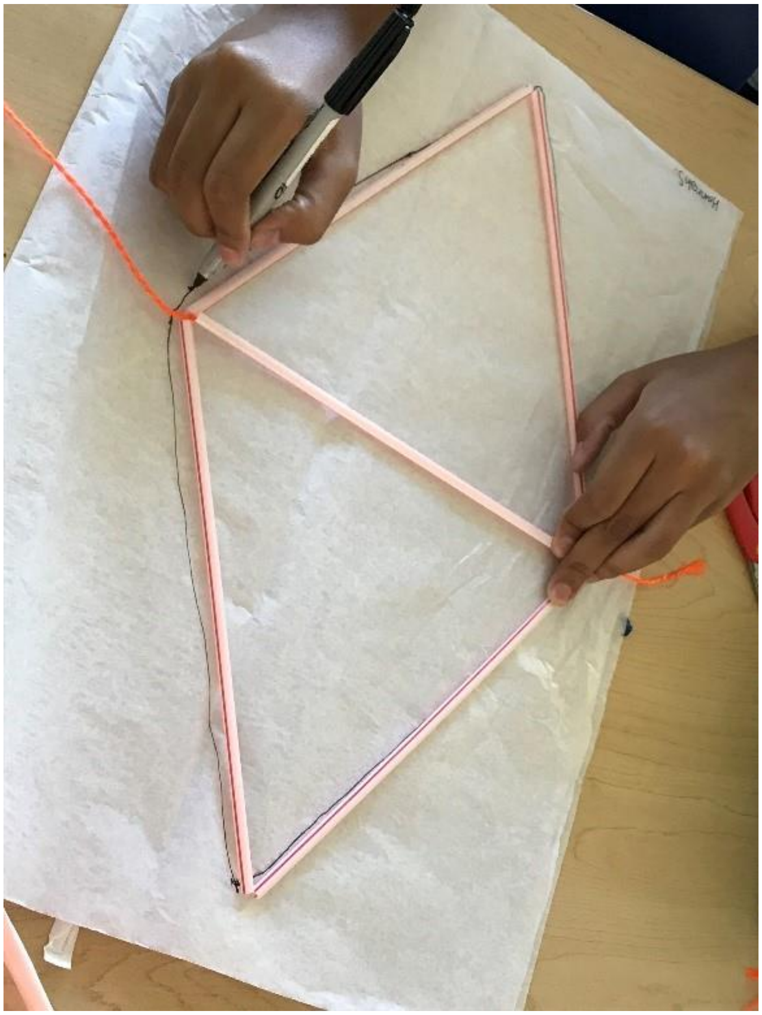

Figure 2: Students create two faces of the equilateral triangle before tracing them to create a net on tissue paper.

Second, after students had created two faces, we had a whole-class discussion about the net of tissue paper covering two faces of the tetrahedron. To create the net, students traced the two sides of the tetrahedron they created (Figure 2), adding tabs around each edge so the tissue paper can later be folded around the straw (Figure 3). We also told students to incorporate extra space for the paper to wrap around the straw on the shared edge of the faces. Selecting from a variety of colored tissue paper gave students choice and incorporated art concepts such as including the meanings of color and the uses of symbol by considering the color pallet of each group's prototype (Grade 9-12 Visual Arts Content Standard 3, National Art Education Association, 2010). Note that students did not yet attach the tissue paper net to their prototype.

Third, we discussed how to make their prototype more artistic using mark making techniques such as hatching, cross hatching, and stippling (Figure 3). On practice paper, students were instructed to practice drawing their physical feature using contour lines and shade dark values using mark making techniques. In doing so, students were exposed to the creation of form with the presence of value through the number of spaces and lines in a given area. Appendix B includes some of the questions we asked students during this practice mark making exercise.

Figure 3: Students with sketches for their tetrahedral kite. Notice the left picture is folded so the student can flip the tissue paper over to work on the other face.

Fourth, we had students attach either blank tissue paper nets or the sketched tissue paper nets to their tetrahedra. We pointed out how the orientation of the tissue paper matters. Students then attached each of their tetrahedron to their group mates to make the prototype (Figure 4). When making the prototype, we (and the students) noticed that masking tape destroyed the beauty of the kite aesthetically because you could see the tape through the tissue paper. We resolved this problem by switching to clear tape for the final product.

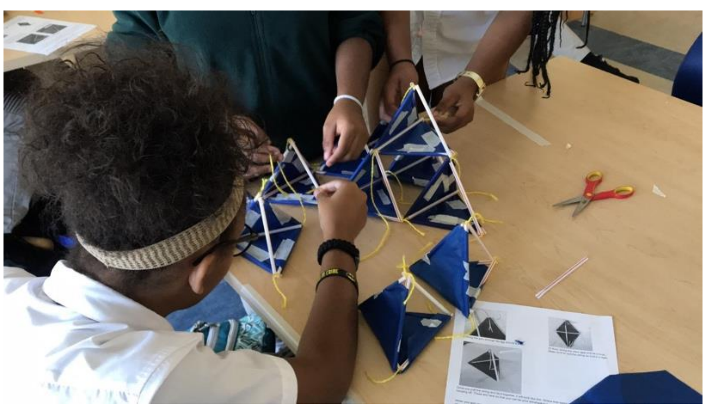

Figure 4: Students create a draft model of their tetrahedral kite.

Creating the prototype and completing a draft of the mark making techniques was important because several errors occurred when students cut and folded the tabs of the tissue paper and securing them onto the tetrahedral kite. This stage allowed students to learn from their mistakes, critique and learn from peer's drawings, and plan on how to manage their time prior to creating a final kite. Additionally, students could experiment with different artistic mark making techniques that took several practices to master. We used the document camera to display several excellent examples so students could make changes to both design and drawing in the next part of the activity.

Part 3: Final Construction and Design of Kite

In Part 3 of the activity, students were asked to select a country and research the economic, social, political, and environmental, and geographical aspects. They were asked to consider the cultural and historical perspectives of their country and the physical features representing the cultural or geography of their selected country. We then gave students another set of supplies and asked them to each create a single, final tetrahedral kite, including mark making on the tissue paper to display value, form, light (contrast), and space that represented their country. Four tetrahedrons can be connected to form a small kite or 16 tetrahedrons to create a large kite, as shown in Figure 1. Additionally, we allowed students to connect their tetrahedra together in any shape they wanted – it did not have to be like the model. In this way we encouraged students to think about factors such as mass and lift and whether their altered design would fly.

Figure 5 shows a close up of the tetrahedron students created and illustrated. Figure 6 shows some of the variation of shapes students created when attaching their tetrahedron. Many students were proud of their illustration outcome and wanted the kite displayed for others to see.

Figure 5: A detailed picture of the mark making on the tetrahedral kite faces.

Figure 6: Variations of final kite design, with the traditional large tetrahedral kite on the left and right and an altered version in the middle.

After their creations, students were challenged to think about what happens when the size of the straw changes (Appendix C). This part of the activity could be optional, if there are time constraints. Because the final tetrahedral kite was much bigger than the prototype, many students wonder if the kite would actually fly. Because the kite was bigger, it weighed more thus required stronger winds to create lift for the kite. This presented challenges that some students raised about the durability of the straw and tissue paper against the force of the wind. Additionally, there are several extension activities for making the mathematics more applicable to high school mathematics content. For example, students could be asked to compute a weight to area factor ratio to evaluate how well a kite will fly (Hosking, 1987).

Conclusion

This activity easily allowed integration between mathematics and visual arts topics, a type of collaboration that is needed and often overlooked (Brazell, 2013). Incorporating mathematics within an art projects aligns with recommendations in *Principles to Actions: Ensuring Mathematical Success for All* (NCTM, 2014), specifically by having students use mathematics to estimate the amount of supplies to build a tetrahedral kite. Additionally, several art standards were incorporated along with aspects of visual arts, science, and engineering concepts.

We found this activity enabled our students to make connections between STEAM concepts in a real world setting that resulted in a beautiful and functional kite shared with the larger community. One student expressed that the kite project addressed “engineering because we had to put it together with straws, tissue paper, and yarn…art because we had to draw our physical feature and make a design to show our climate”. Another student expressed that “we learned who made the first kite and what other countries called it; and what it meant to them”. When students flew their kites, parents, spectators, and even the engineering teacher of the school were impressed with the finished product. Most importantly, spectators who participated in the kite festival learned an interesting connection between art and mathematics that is often overlooked, which students articulated with comments such as, “we used the Pythagorean theorem to find the height of triangles from this kite project”. There were doubts that the tetrahedral kite would be able to fly, but the students saw the traditional model does fly and began using mathematics, physics, and engineering terminology for hypothesizing why the nontraditional models did not always fly. One of the most rewarding results from this project was seeing our 9th grade students explain these ideas to other (often older) students, parents, and members of the larger community.

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Appendix A – STEAM Activity Part 1 Questions

After examining the tetrahedral kite in front of you, answer the following questions:

1. The word *tetrahedral* is an adjective that describes a shape. The word *tetrahedron* is a noun that is an actual shape.
    a. What is a tetrahedron? Use the internet help come up with a definition and a simple 3D sketch.
    b. The word tetra comes from a Greek word meaning 4. Where is 4 seen in your picture of a tetrahedron?
    c. Why is the kite in front of you called a tetrahedral kite? What is similar to the definition of tetrahedron and what is different?

2. You might remember that in mathematics, the word *net* refers to the 2D outline that, after folding, becomes a 3-D shape.
    a. Draw a 2D shape that, when folded, becomes a 3D tetrahedron.
    b. Draw a 2D shape that, when folded, can be placed on the kite to match the model.

3. Next week you will be constructing your own tetrahedral kite. Answer the following questions to provide an estimate of how much supplies you will need:
    a. How many **straws** will you need to create a single tetrahedron?
    b. The straws I plan on buying are 7.75 inches. Estimate the length of **string** will you (individually) need to create a single tetrahedron (remember the string goes through each of the straws). Show your work so I can make sure you come up with a reasonable estimate.
    c. What size **tissue paper** will you (individually) need to create a single tetrahedron suitable for the kite? For this question, you will need to consider the surface area of the two faces of the tetrahedron. Consider the shape of these faces, and how to compute the area of that shape.
    d. What color of tissue paper will you (individually) use on the faces of your single tetrahedron kite? How does this color scheme match up with those in your group?
    e. For your entire group to create the tetrahedral kite in front of you, how many straws, how much string, and what size tissue paper will you need to create the kite? I will get extra in case there are mistakes but give me the minimum amount your group will need. Show your work on how you computed this.

4. When I go and purchase the supplies, what do you recommend? (circle one)
    a. The straws (a) are all the same size or (b) doesn’t matter what size.
    b. The string (a) stretches a lot when pulled, (b) stretches some, or (c) does not stretch at all.
    c. Tissue paper that is (a) lightweight or (b) heavy.

Appendix B - STEAM Activity Part 2 Questions Addressing Art Standards

VA: Cr2.1: Artists and designers experiment with forms, structures, materials, concepts, media, and art-making approaches.

1. What are the steps in drawing to get to the final outcome?
   a. What elements of art are needed to get started?
   b. What kind of shapes are present to simplify the observation and drawing process?
   c. What are contour lines and gestural drawing, and how do these help artist in the initial phase of drawing?

2. How does the choice of material affect the outcome and techniques used in art?

3. How can we create drawings that reflect the lightness and darkness of a physical feature without shading?

4. How can ink or marker show value if shading is not applicable?

VA: Cr2.2: Artist and designers balance experimentation and safety, freedom and responsibility while developing and creating artworks.

1. What are the different solutions that can be taken to display artistic intentions?

2. What is appropriation, fair use, and copy right in works of art?

3. What are some safety concerns when using sharpie markers in terms of space and length of use?

4. What are some precautions in using tissue paper with factor such natural forces and adhesive?

VA: Re7.2: Visual imagery influences understanding of and responses to the world.

1. How does color express ideas and senses?

2. In what ways can visual imagery be used to express conceptual ideas?

3. How can a drawing of a physical feature relate back to cultural geography?

4. How does physical feature affect culture and cultural diffusion?

Appendix C - STEAM Activity Part 3 Questions

1. Complete the table using what you know about surface area. Show your work and include units.

Size of straw used	8 inches	16 inches	24 inches	4 inches
Draw the concept.				
Determine the total surface area of the tetrahedron.				
Determine the area of tissue paper needed to cover two sides of a single tetrahedron.				

2. Note that in the first two columns of the table, the second column examines a tetrahedron that has double the size of the straws as the first column (16-inch straws versus 8-inch straws).
    a. Is the total surface area of the 16-inch sided tetrahedron double the total surface area of the 8-inch sided tetrahedron?
    b. How many times bigger is the total surface area of the 16-inch sided tetrahedron in comparison to the total surface area of the 8-inch sided tetrahedron?

3. Note that in the first and third columns of the table, the third column examines a tetrahedron that has triple the size of the straws as the first column (24-inch straws versus 8-inch straws).
    a. Is the total surface area of the 24-inch sided tetrahedron triple the total surface area of the 8-inch sided tetrahedron?
    b. How many times bigger is the total surface area of the 24-inch sided tetrahedron in comparison to the total surface area of the 8-inch sided tetrahedron?

4. Note that in the first and fourth columns of the table, the fourth column examines a tetrahedron that has half the size of the straws as the first column (4-inch straws versus 8-inch straws).
    a. Is the total surface area of the 4-inch sided tetrahedron half the total surface area of the 8-inch sided tetrahedron?
    b. How many times bigger is the total surface area of the 4-inch sided tetrahedron in comparison to the total surface area of the 8-inch sided tetrahedron?

5. Complete the table:

If I multiply the side lengths of a tetrahedron by…	…then the surface area of the tetrahedron changes by a factor of…
2	
3	
½	
n	