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Original Article

Using Origami to Build the Spatial Visualization Skills Students Need to Excel in the STEM Field

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Abstract

STEM and STEM education have been placed in the national spotlight because of below average student achievement in mathematics, science, engineering, and technology disciplines. Traditional instructional methods have not adequately prepared students for current college and workforce demands Using origami to increase concepts and abilities in geometry, especially the concept of spatial reasoning, provides alternative lessons for teachers and may increase engagement and motivation of students in learning. Hands-on, origami lessons can start in elementary school and continue to be integrated into geometry mathematics lessons throughout high school. These lessons make geometry tangible and connect students to real world applications in which students will think critically and learn to problem solve.

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1. Introduction

STEM and STEM education have been placed in the national spotlight because of below average student achievement in mathematics, science, engineering, and technology disciplines (National Center for Education Statistics (NCES) 2015). In fact, many high school graduates are now entering college and the workforce lacking the 21st century skills, such as critical thinking and problem solving, necessary to be successful in our ever-changing society (Greenhill, 2010; Sheffield, Morgan, Blackmore, 2018). Traditional instructional methods have not adequately prepared students for current college and workforce demands (Hmelo-Silver, 2004; Ronis, 2008; Soule Warrick, 2015; Sheffield, Morgan, Blackmore 2018). In fact, in most schools, the core discipline areas of mathematics, technology and science continue to be taught separately with little or no integration (Blackley Howell, 2015). In 2015, the President's Council of Advisors on Science and Technology (PCAST) found that a large gap existed between the demands of people prepared to work in STEM fields and the inadequate preparation in both K-12 and higher education. As well, in 2015, Trends in International Mathematics and Science Study (TIMSS) reported no significant change in mathematics or science scores (NCES, 2020). In 2019, the National Assessment of Educational Progress (NAEP) reported higher mathematics scores in grade 4 and lower mathematics scores in grade 8 (NCES, 2020).

The question before us is how do we address the issues in STEM education as well as begin to bridge the gap so that students graduate high school and college ready to be successful in the STEM workforce?

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2. STEM and Spatial Visualization Skills

Based upon the national and international assessments (NCES, 2020), one area in the STEM pipeline that students consistently score low on is mathematics; specifically, geometry. Geometry is recognized as an important part of the kindergarten through grade twelve mathematics curriculum. It is through geometry that students begin to develop an understanding of "geometric shapes and structures and how to analyze their characteristics and relationships" (National Council of Teachers of Mathematics (NCTM) 2000, p.41; NCTM, 2014; NCTM, 2020). Part of this development includes the building of spatial visualization skills. Defined as "building and manipulating mental representations of two and three-dimensional objects and perceiving an object from different perspectives" (NCTM, 2000, p. 41; NCTM 2014; NCTM 2020), spatial visualization is viewed as an essential part of geometric thought.

Support for the connection between spatial visualization skills and STEM comes from longitudinal studies. For example, in a thirty year longitudinal study, Shea, Lubinski, and Benbow (2001) found that the spatial visualization skills of intellectually talented high school students predicted their interest in and pursuit of a STEM career, more so than their verbal and quantitative abilities. Twenty years later, the same students who had better spatial visualization and mathematics skills reported engineering, computer science, and/or mathematics as their favorite courses, college majors, and career pursuits, compared to individuals with better verbal abilities (Lubinski Benbow, 2006). Further follow-up revealed a link between better spatial visualization skills and career success as measured by patents and peer-reviewed publications, especially in STEM fields (Kell, Lubinski, Benbow, Steiger, 2013). The spatial visualization-STEM connection is not limited to talented students. In 2009, Wai, Lubinski, and Benbow conducted research using a stratified random sample of high school students. Spatial visualization skills again predicted STEM education and career choices. This research suggests a connection between spatial visualization skills in high school and STEM outcomes. However, high school may be too late for developing the spatial visualization skills needed for STEM education and career choices. Developing spatial visualization skills well before high school may have a more pronounced impact on STEM outcomes.

3. Teaching Geometry and Spatial Visualization Skills Through Origami

Today, some people think that origami is a fun activity for children. However, for other people, the word "origami" points to extremely complex organic and geometric shapes, which find applications in different domains, from designing safer airbags in cars to telescopes. Origami is closely related to science and can be perfectly integrated within the STEM disciplines. There are three interdisciplinary subjects that exist, namely: origami mathematics, computer origami, and origami engineering technology (Turner, Goodwine, Sen, 2015). Origami mathematics studies the mathematical principles in origami. Computer origami uses computers to seek new solutions and reasoning for problems caused by origami. Origami engineering technology uses the origami approach to solve engineering problems encountered in practical use (Qin Dai, 2013). With the emphasis on integrating content today, origami is becoming more and more popular in today's mathematics and STEM instruction. Origami as a type of hands-on activity can help students better understand mathematical concepts and increase students' ability to communicate mathematically (Cipoletti Wilson, 2004). As well, students begin to understand and experience some of the complexities and interconnections of aspects of life and perseverance when they practice origami (Sze, 2005). Certain attributes of origami provide the potential for its use in teaching and doing mathematics. Some of the attributes of origami are:

- Creating an origami model involves following a procedure.
- The procedure involves the spatial manipulation of the paper.

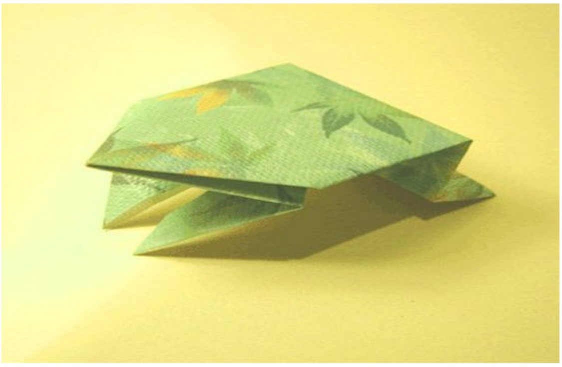
- Different models can be related to one another by examining the modifications of general procedures.
- Teaching the creation of a model involves communication, either orally or through directions (text and diagrams) or perhaps computer based hypermedia.
- Teaching in origami, by nature and convention, is cooperative, applied, and student centered.

Listed below are examples of how teachers may integrate origami at the elementary, middle school, and high school levels to teach geometry, especially spatial visualization skills, as well as other mathematical content.

3.1. Elementary School

Teachers at the elementary level can use origami to teach geometry-shapes and congruency, patterns, fractions, and measurement of lines, shapes, and angles, as well as many other mathematical standards. Listed below is a STEM challenge that incorporates geometry and measurement and data (Nakashima, 2016). The goal of the challenge is to have the largest combined jumping distance with each frog jumping only once.

Figure 1. Origami Jumping Frog STEM Challenge



Challenge: Students will create the most origami jumping frogs in 45 minutes and then have the longest combined jumping distance using each frog only once.

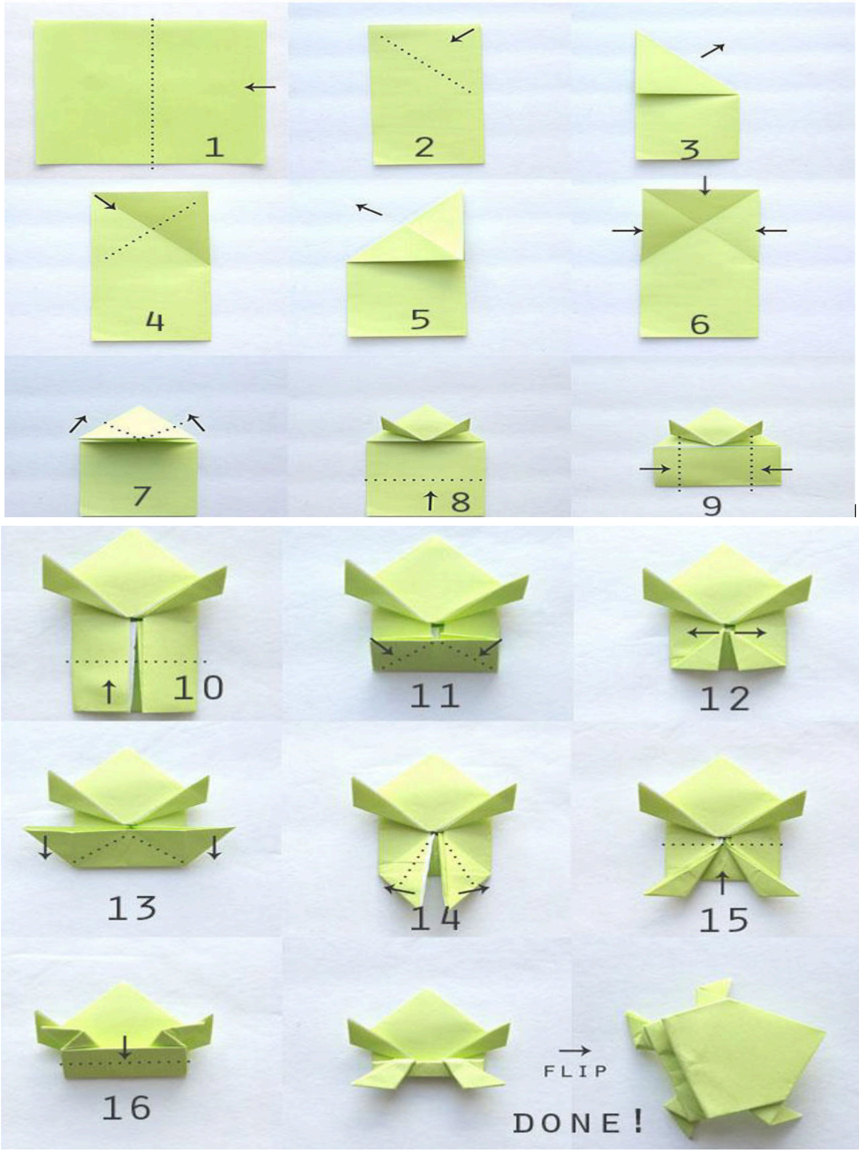
Materials: variety of paper squares, tape measure, timer.

Mathematical Domains: Geometry, Measurement & Data

Directions:

1. Choose the type and color of paper you want to use.
2. Follow the paper folding directions to make the jumping frog.
3. Make sure the paper is folded well or the frogs will not jump as far as they can.
4. Your goal is to make as many jumping frogs as you can in 45 minutes and then have the longest combined jumping distance using each jumping frog once.
5. Practice jumping your frogs.
6. Record the distance that each frog jumped in the table provided on the activity sheet.
7. Calculate the total combined distance.

Directions for Folding



Student Lab Sheet: Origami Jumping Frog Challenge Name ____________________

Make a hypothesis. How far, in a combined distance, will your frogs jump if each frog is jumped once?

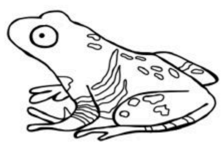
Try it! Without the timer, use the direction sheets to make one frog. How far does it jump?

My First Frog Data

Jump your first frog three times. Record the three jump distances.

Combined Jump Distance:

Try it again! You have 45 minutes to make as many origami frogs as you can. What strategy did you use to make the most jumping frogs? Which was more important, quality or quantity? Why?

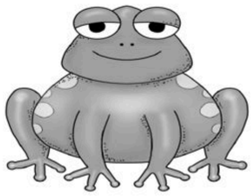


Time to jump those frogs! Your goal is to have the farthest combined jump distance, jumping each origami frog only once. Record each jump and the total combined distance below.

How far did most of your frogs jump? Was it a predictable distance? Why or why not?

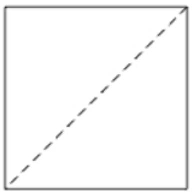
What technique did you use to jump your frogs?

What were some of the challenges of working with origami frogs?

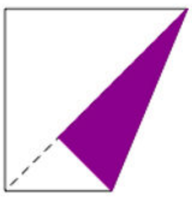


3.2. Middle School

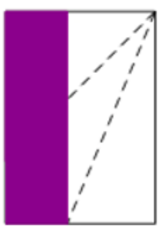
This task (illustrativemathematics.org) examines the mathematics behind an origami construction of a rectangle whose sides have the ratio (2:1). Such a rectangle is called a silver rectangle. Beginning with a square piece of paper, first fold and unfold it leaving the diagonal crease as shown here:



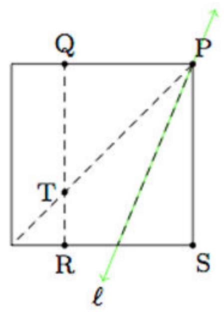
Next fold the bottom right corner up to the diagonal:



After unfolding then fold the left hand side of the rectangle over to the crease from the previous fold:



Here is a picture, after the last step has been unfolded, with all folds shown and some important points marked. In the picture T is the reflection of S about l.



1. Suppose SP is the side length of our square. Show that $PT = SP$.
2. Show that ΔPQT is a $45 - 45 - 90$ isosceles triangle.
3. Calculate PQ and conclude that $PQRS$ is a silver rectangle.

3.3. High School

Challenge: Surface Area and Size:

Why do Small Things have Big Impacts?

In this activity, you will explore the relationship between surface area, volume and size by making and examining origami cubes. (New Jersey Department of Education, 2020).

QUESTION: *How are surface area, volume and size related?*

Academic Language:

- Volume: The amount of space an object occupies (Volume = length * width * height).
- Surface Area: The total area of the surface, or outer-most layer of an object (Surface Area of a Cube = 6 * (length *width)).

MATERIALS:

- 1 large cube net (5 cm per side)
- 8 small cube nets (2.5 cm per side)
- Ruler
- Scissors
- Tape

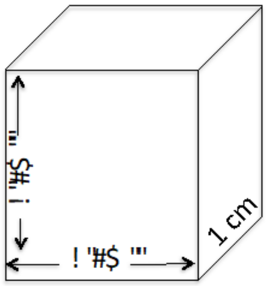
DIRECTIONS:

- Cut out all 9 cube guides (called nets).
- Fold the paper inwards along the bold lines until you make a cube-shape.
- Tape along the edges to hold the cube together.
- Continue until all 9 cubes are completed.

ANALYSIS: (Remember to show all work and complete units)

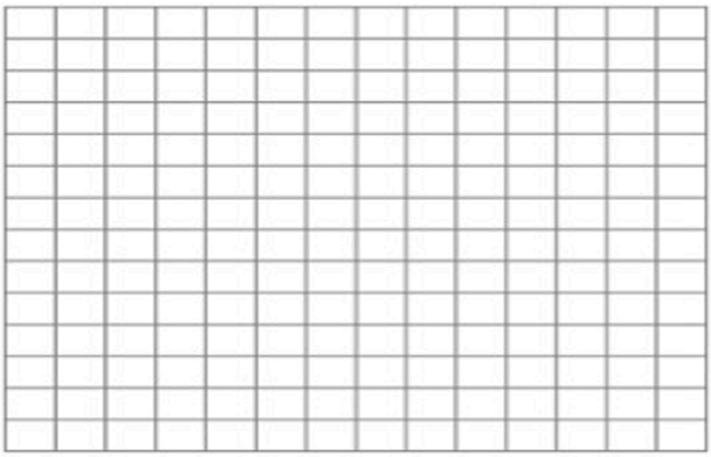
Volume:

1. Using the formula for volume above, calculate the volume of the large cube.
2. Compare the volume of the large cube to that of all the small cubes combined.
3. Calculate the volume of an even smaller cube with sides of 1 cm each. How many of these cubes would you need in order to equal the volume of the large cube?



Surface Area:

4. Using the formula for surface area above, calculate the surface area of the large cube.
5. Calculate the surface area of 1 small (2.5 cm per side) cube. What is the surface area of all 8 small cubes combined?
6. Calculate the volume of 1 small cube. What is the volume of all 8 small cubes combined?
7. Compare the surface area of the large cube to that of the small cubes.
8. Calculate the surface area of a cube with 1cm sides. What is the surface area of 125 of these cubes combined?
9. Using the graph paper below, graph the relationship between you've seen so far between total surface area and size of particles. Be sure to label the scale for each axis.



Extension: Using the formulas for surface area and volume, find the mathematical relationship between surface area and volume.
Using *evidence* from your work above, construct a claim that addresses the question, how are surface area, volume and size related?

4. Summary.

Scores on national and international assessments of mathematics, specifically geometry, have been traditionally low. STEM and the STEM disciplines are now in the spotlight with 21st century skills that will prepare students for college and career readiness. Using origami to increase concepts and abilities in geometry, as well as spatial reasoning provides alternative lessons for teachers and may increase engagement and motivation of students in learning. Hands-on, origami lessons can start in elementary school and continue to be integrated into geometry mathematics lessons throughout high school. These lessons make geometry tangible and connect students to real world applications in which students will think critically and learn to problem solve.

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