Math Projects Integrate Engineering Design & Artistic Creativity

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***Abstract* – The Cincinnati Engineering Enhanced Math and Science (CEEMS) Program, funded by the National Science Foundation, DUE #1102990, empowers secondary math and science teachers to integrate the engineering design process and challenge-based learning into the courses they teach. Some of the curricular materials developed by CEEMS participating teachers also incorporate the fine arts into the design process, thus increasing student engagement and demonstrating the importance of a multi-disciplinary approach to learning. This paper describes seven challenge-based learning endeavors developed for middle school and high school math classrooms that demonstrate the connection with math and fine arts. One curricular unit is described in detail to highlight the incorporation of engineering design and challenge-based learning, while the other six are summarized to provide other examples. Traditionally, math instruction features the teacher as the "sage on the stage" and students working individually to apply formulas in order to find the "right" answers. In contrast, CEEMS' pedagogical approaches result in student-directed instruction, which includes cooperative learning groups using creativity and critical thinking to develop unique solutions to design challenges.**

Index Terms – challenge-based learning, engineering design process, math instruction, STEaM

CINCINNATI ENGINEERING ENHANCED MATH AND SCIENCE PROGRAM (CEEMS)

The Cincinnati Engineering Enhanced Math and Science Program (CEEMS), supported by the National Science Foundation (DUE #1102990), seeks to change secondary teachers' instructional practices by introducing them to two student-centered pedagogies--challenge-based learning (CBL) and the engineering design process (EDP). Secondary teachers (7^{th}-12^{th} grades) in STEM disciplines participate in two summers of engineering coursework and professional development program to help them to develop curricular materials utilizing these pedagogies. Although it was not a program requirement, some curricular materials also incorporated art and thus can be classified as STEaM (science, technology, engineering, arts, mathematics).

Challenge-based learning is a multi-disciplinary approach to education that encourages students to leverage content knowledge from various disciplines, technology, and creativity to solve real world problems**.** By giving students the opportunity to focus on a challenge of global significance and apply themselves to developing local solutions, CBL creates a space where students can direct their own research and think critically about how to apply what they learn. Challenge-based learning starts with a big idea. Students are challenged to identify an essential question related to the big idea and a challenge that attempts to solve the big idea. Students identify guiding questions that will need to be answered to help them solve the challenge. After creating in groups a unique solution to the challenge, students communicate that solution to others. Similar, although not identical, pedagogies include problem-based learning, design-based learning or project-based learning. Essential to CBL is the student engagement piece. As much as possible, students direct the process, as opposed to having the teacher dictate step by step how and what they will learn.

CEEMS adds a unique twist to the student-centered CBL approach by employing the engineering design process as the vehicle by which the students solve the challenge. In this marriage of the two approaches, teachers use CBL to get students engaged and interested in the problem and then guide them to use the engineering design process to seek multiple solutions to the challenge presented. We describe in the following one detailed example of a middle school math teacher's efforts to carry this out while embedding the involvement of art, design, and the language arts.

RE-DESIGNING CEREAL BOXES

A current participant in CEEMS, middle school math teacher Ms. Gina Ogden, developed a curricular unit designed to solidify seventh grade students' understanding of surface area and volume of three dimensional shapes. In addition to increasing their math knowledge, Ogden incorporated the engineering design process, visual art and language arts into the unit thus demonstrating that real world problems require application of multiple disciplines in order to develop creative, viable solutions.

As a hook to get the students engaged in the unit, Ogden gave the students two articles to read about changes in cereal box design over time and showed them a short YouTube video about how Kellogg is considering changes to cereal packaging that reduce the negative impact on the environment. A class discussion ensued, whereby the

teacher allowed the students an extended period of time to share their different opinions about cereal box design, including what appealed to them as consumers. Latching on to the big idea of how to protect the environment, students identified the essential question for the unit as the following: "What impact does the size of a cereal box have on the environment?" The teacher then challenged the class to act as an advertising firm that has been hired by General Mills to change the box of their popular cereal, Cheerios. The box must use less cardboard than the current design while holding the same volume of cereal. The students also had to update the graphics on the front of the box to appeal to consumers and design a game for the back of the box in the shape of a trapezoid. Creation of the game helped fulfill another math learning outcome related to the study of geometric figures. In addition, students were required to draft a letter to the General Mills CEO detailing their changes, explaining the reasons for those changes, and persuasively defending why their new design would have a greater appeal to consumers.

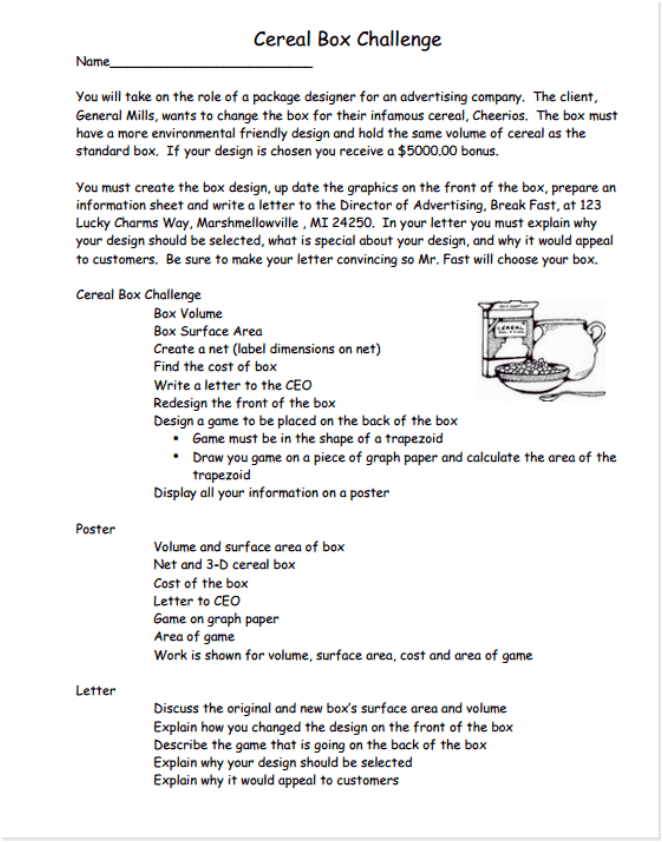
Rather than telling the students what content they needed to learn first in order to solve the challenge, Ogden asked the students to identify some guiding questions. Examples of some guiding questions related to this challenge include:

- What different sizes of cereal boxes can you buy in a store?
- What did you notice about the packages and the products inside?
- Would you consider these packages to be environmentally friendly?
- How do cereal boxes compare in terms of surface area?
- How does the volume of different cereals (boxes) compare?
- Why are some boxes of cereal smaller or larger than others?
- What could you do to change the packages to reduce the excess packaging?
- How does the box design affect the shelf storage and visual appeal?
- What is the relationship between the surface area of a box and the volume of the cereal in it?
- How do you calculate the surface area and volume of a rectangular prism?

Using the engineering design process and their knowledge of surface area and volume, students, working in teams, brainstormed possible alternative box designs, created a prototype of their group's best idea, and tested and evaluated the effectiveness of that prototype. The testing process was simple, but powerful: twenty ounces of Cheerios was poured into the prototype to see if the new box with a smaller surface area contained sufficient volume. If the cereal overflowed, students needed to modify their design, create a new prototype, and re-test.

The student teams then proceeded to develop new graphics for the front of their re-sized box and the trapezoid shape game for the back, followed by the letter to the General Mills CEO, and then all deliverables were organized on a poster for final group presentations.

As shown on Figure 1, the challenge involved application of math skills, but it also incorporated student creativity, artistic talent, and persuasive writing. When Ogden re-teaches this unit in 2014, she plans to involve the art teacher to help students with the front and back designs. Not only will this emphasize to students the need for a multi-disciplinary approach to solve problems, it will also free up more time in math class to devote to real world learning. Teachers are often reluctant to undertake projects like this due to a perceived lack of time. The pressure of standardized testing forces teachers to try to squeeze as much academic content as possible in math class, making project and group work seem superfluous. If some of the more creative elements of the project can be completed in art class, time in math class can be solely devoted to focusing on the mathematical dimensions of the project. Ideally, the letter to the General Mills CEO could be incorporated in a language arts class. This would be possible if the middle school was organized in teams, meaning that a group of students share the same Language Arts, Math, Science and Social Studies teachers.



Cereal Box Challenge

Name_____

You will take on the role of a package designer for an advertising company. The client, General Mills, wants to change the box for their infamous cereal, Cheerios. The box must have a more environmental friendly design and hold the same volume of cereal as the standard box. If your design is chosen you receive a $5000.00 bonus.

You must create the box design, up date the graphics on the front of the box, prepare an information sheet and write a letter to the Director of Advertising, Break Fast, at 123 Lucky Charms Way, Marshmellowville , MI 24250. In your letter you must explain why your design should be selected, what is special about your design, and why it would appeal to customers. Be sure to make your letter convincing so Mr. Fast will choose your box.

Cereal Box Challenge

- Box Volume
- Box Surface Area
- Create a net (label dimensions on net)
- Find the cost of box
- Write a letter to the CEO
- Redesign the front of the box
- Design a game to be placed on the back of the box
  - Game must be in the shape of a trapezoid
  - Draw you game on a piece of graph paper and calculate the area of the trapezoid
- Display all your information on a poster

Poster

- Volume and surface area of box
- Net and 3-D cereal box
- Cost of the box
- Letter to CEO
- Game on graph paper
- Area of game
- Work is shown for volume, surface area, cost and area of game

Letter

- Discuss the original and new box's surface area and volume
- Explain how you changed the design on the front of the box
- Describe the game that is going on the back of the box
- Explain why your design should be selected
- Explain why it would appeal to customers

FIGURE 1

According to pre- and post-test results, students in all three block periods recorded, on average, statistically significant increases from their pre-assessments to their post-

assessments. Periods 1/2, 3/4, and 5/6 recorded an average percent increase of 41%, 40%, and 68%, respectively. Of the 69 students in Ogden's classes, only 10 scored lower on the post-test than the pre-test. Most of those students had relatively high scores on the pre-test initially. Please see Table I for results.

TABLE I
PRE-POST PERCENTAGE INCREASE ON OGDEN'S CEREAL BOX CHALLENGE UNIT

Class Periods	Average Percentage Increase from Pre to Post-Test	Results of Paired T-Test & Statistical Significance (yes or no)
1/2	41%	Yes-0.000285802
3/4	40%	Yes-0.001106278
5/6	68%	Yes-1.87964E-05

In addition, Ms. Ogden was pleased because students who were typically disengaged in the learning process displayed excitement about this project. They would come into the classroom and immediately get to work on their cereal boxes; the real world challenge seemed to motivate them in a way that traditional teaching did not.

FIGURE 2

OTHER EXAMPLES OF MATH AND DESIGN

Teachers participating in the CEEMS project have produced other curricular materials that require students to use their creativity and artistic ability while applying math content. For example, Mrs. Katie Powers, a high school geometry teacher in an urban setting where 85% of students are minorities and 69% are economically disadvantaged, created three units for the 2012-2013 school year that centered around the theme of improving their school infrastructure and climate. In her first unit, students utilized knowledge of geometry to design blueprints of their ideal learning space or classroom and presented their ideas to the school board. This was a relevant project for students as the school board, at this time, was considering placing a bond issue on the ballot that, if passed, would result in construction of a new school building.

Powers' second unit offered a special opportunity to utilize creativity. Students were challenged to create a new sign for their high school that would convey a positive image to the community. Working in groups, students sketched several designs and chose their favorite. Students needed to calculate how large the sign needed to be in reality and then create a proportional model to scale. Students then had to paint one letter in the size it would be on the sign. They had to calculate exactly how many ounces of paint would be needed, using their knowledge of perimeter and surface area of polygons. The teacher gave them the paint so the students could demonstrate for themselves if the amount of paint was calculated precisely.

Powers' third unit focused on improving the cafeteria food by adding ice cream cones to the menu. Students applied their knowledge of finding surface area and volume of conical figures to create ice cream cones that could hold up to six ounces of ice cream with minimal surface area. Powers provided pre- and post-assessment scores for this unit. All three classes implementing the unit demonstrated statistically significant increases from pre- to post-test: 143%, 72%, and 241%, respectively.

While the goal of CEEMS is not to create STEaM projects, some naturally integrate artistic skills as students are challenged to think creatively and develop unique solutions to problems. One of Ogden's units scheduled for the 2013-2014 school year will challenge students to create a tessellating tile for wrapping paper. This will help the students grasp the geometric concept of transformations in tessellations. Seventh grade math teacher Mrs. Jamie Dicks will have her students design what they envision as the "perfect" desk using surface area, volume, and scale drawings. Students will employ their creativity as they visualize and build a scale model of their ideal desks. Another branch of fine arts is employed in a curricular unit created by pre-calculus teacher, Mr. David Macmorine, a math teacher at the School for Creative and Performing Arts. He will challenge his students to work in teams to design and create three instruments, a woodwind, a percussion instrument, and a stringed instrument. The instruments must be tuned within 5 Hz range of the note A (440 Hz). This exercise will help them grasp the concept of waves and their description as sine or cosine functions, while simultaneously challenging them to use their artistic and musical imaginations in the creation of the instruments.

Adding art and design to the study of mathematics increases student engagement and demonstrates the importance of inter-disciplinary work to students. Success in the 21st Century will require students to be able to innovate using multiple disciplines and use critical thinking to discover unique solutions to problems that have more than one "right" answer. CEEMS math teachers, in particular, are finding innovative ways to help students apply the subject matter, in contrast to teaching math in the traditional "sage on the stage" format.

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