STEAM Approach by Integrating the Arts and STEM through Origami in K-12

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***Abstract*—While science, technology, engineering and math hold the fastest growing fields today, only 44% and 36% of students are math and science ready, respectively, to enter college. By integrating the arts into STEM, a four-part origami based curriculum has been developed, which combines the topics of renewable energy, architecture design, 3D CAD design and printing, and mathematic, science, and engineering principles. The modules are composed of familiar engineering education tactics to get students to think outside of the box like an engineer. Students reverse engineer origami pieces, build an origami chair using the design process, and learn the topic of renewable energies through interactive games. The final module pulls the knowledge gained from the first three together. The students design and 3D print origami structures that are energy efficient and utilizes at least one source of renewable energy. Students go through the design process with brainstorming, prototyping, and working models.**

The K-12 Next Generation Science Standards for science and engineering has eight practices. Origami Meets STEAM practices all eight including: (1) Asking questions and defining problems, (2) Developing and using models, (3) Planning and carrying out investigations, and (6) Instructing explanations and designing solutions. This project has been introduced to 9^{th} and 10^{th} grade geometry classes. Surveys were given to gauge the effectiveness of activities with the students, teachers, and participating graduate students. This is a work in progress and results of the surveys and work are still being processed.

***Index Terms*—K-12 STEM Education, Origami, NGSS, Geometry.**

I. Introduction

As the need for engineering based careers steadily rises, preparing our future work force is vitally important. Today, only 44% and 36% of students are math and science ready to enter college, respectively, which are the foundation to a engineering degree. To counteract this problem, the National Science Foundation, NSF, and the National Academy of Engineering, NAE, have teamed up and created the STEM K-12 Fellowship Program, which places engineering Ph.D. candidates into K-12 classrooms to introduce the fourteen grand challenges that represent our need to solve problems for the future [1], [2].

This work focuses on STEAM (Science, Technology, Engineering, Art, and Mathematics) education in 9-12. The addition of art into the STEM subjects is a cross disciplinary movement, which explores new opportunities of unique practices and diverse products [3], [4]. The ancient Japanese craft of folding paper into geometric structures, origami, provides students with the addition of art, which allows higher interest with more creativity. Origami has been proven in many studies to improve spatial thinking and cognitive skills at various grade levels [5], [6], [7]. Origami is a defined field of engineering with many direct applications in the medical, mechanical, and structure disciplines [8], [9]. The use of art has been seen integrated into STEM subjects to enhance creativity of STEM students and broaden interest [10].

In the Next Generation Science Standards, NGSS, for science and engineering practices, there are eight practices that should be taught in K-12 [11]. Through these standards and the NAE Grand Challenges, a four-part origami-based curriculum has been developed, which combines the topics of renewable energy, architecture design, 3D CAD design and printing, and mathematic, science, and engineering principles. The modules focus on teaching students geometric principles hands-on through origami, reverse engineering, the engineering design process, six main renewable energy methods, and presenting and communication skills. While trying to bridge the gap between high school and university this work follows previous work by the authors of breaking down college-level material and integrating it into the high school classroom [12], [13], [14].

In addition to the challenge of preparing students to be equipped with engineering mindsets, there is the challenge of raising energy awareness. One of the largest topics repeatedly seen in the NAE grand challenges is energy. These challenges stem from the world's energy consumption rising at an exponential rate while the natural energy sources continue to dwindle. Raising awareness with children about challenges involving energy will help create a sense of familiarity and potentially, a desire to follow career paths that deal with solving these future energy challenges. This is seen in many studies of energy awareness that have been conducted over the years [15], [16], [17], [18].

II. METHOD

This work is broken down into four main sections with the common goal of generating interest in engineering while raising awareness of the energy crisis: (1) Think Like an Engineer, (2) Origami Chair (3) Renewable Energy (4) Renewable Energy Origami Building. With interest and awareness comes the need to solve the problem at hand. This paper focuses on the developed curriculum and the preliminary results of the curriculum being integrated into two 9th and 10th mixed-grade geometry classes. There are two specific cohorts that were taught the curriculum for a total of 46 students: Cohort A and B, 32 and 14 students, respectively. The curriculum was taught by the teacher of the course and a NSF K-12 STEM fellow. To give the students a sense of structure and practice, as well as familiarity, the fellow was in the classroom at least once a week. Each module is explained in depth in the following sections, but typically, each module begins with the fellow giving a brief interactive lecture to the students lasting no more than 15 minutes. Each module was developed to be completed within two or three days of 40 to 60 minute class periods. The classroom is completely student-centered with students completing hands-on personalized objectives. At the end of each module, students are asked to present their findings and ideas to the class. The students are required to use at least one visual aid during their presentation. This is to not limit students to a slide deck, but rather enhances their creativity.

A. Think Like an Engineer

The main focus of the first module is to get the students to creatively start thinking and to provide them with the mindset that there is no right or wrong answer, but rather a reasoning and solution to a given challenge. This begins with a worksheet and class discussion. The worksheet has the students answer questions that could be interpreted in various ways. For example, one question is, "How many vehicles are on the Ben Franklin Bridge at any give time?" This should provoke the students to ask more questions: "What counts as a vehicle?" "Are the cars moving?" "What is the given time?" With these type of questions the students should be encouraged to define their own answers. This allows for the students to understand that the answer is not the most important part of the question, but rather how they went about to solve the presented problem. The day is ended with a take home challenge to engage the students past the classroom. In this particular execution, the students were provided with the challenge of trying to cut a 3x5 inch index card in a way that he or she could fit their head through it, which was based around the topic of concentric circles, which was being taught in the geometry class at the time.

For the second part of the module, the focus moves to a more hands-on engineering point of interest, reverse engineering. A brief class discussion is conducted on what reverse engineering is and why it is important. Reverse engineering is the process of duplicating an existing component, sub assembly, or product without the aid of drawings, documentation, or computer model. It is an important procedure in engineering to

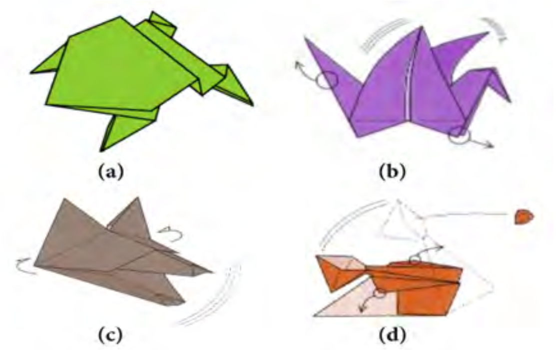

Fig. 1. (a) The jumping frog origami structure, which when pressure is placed on the middle of its back the frog leaps up due to the spring like folding in the legs. (b) The flapping crane origami structure, which when the user holds the front of the base and pulls up on the tail the wings will flap up and down. (c) The barking wolf origami structure, which when the sides of the head are pushed in the mouth will open and close. (d) The catapult origami structure, which with side flaps are pulled outwards the catapult will launch the paper in the cradle into the air.

understand how something works as a starting point to improve upon the design. This links the NGSS practices, (2) using models, (3) planning and carrying out investigations and (8) obtaining, evaluating, and communicating information, to this module.

In small groups, students are provided with one of the four functional pieces of origami, approximately 6 by 6 inches, Figure 1. With a provided worksheet, students progress through the reverse engineering process: prediction, observation, disassemble, analyze, test, and documentation. To help the students understand the importance of this process, they are asked to improve upon the origami piece in at least one way. To conclude the project, each group presents their results with the classroom while providing an explanation of their findings and added design. From this module, students are also able to visualize, describe, and label shapes, as well as determine areas of shape and geometric angles.

B. Origami Chair

Once students have grasped the basic geometric concepts of origami, they are able to utilize them in developing an origami chair, which introduces the engineering design process: define, develop solutions, and optimize, the NGSS design process [11]. A brief interactive lecture is given to provide knowledge of the path that should be taken during the project, prescribed with applicable examples along the way. During the lecture, the design criteria is given. Much like the well known cardboard chair module, the chair must be able to hold the equivalent of a human being. Since the chair is only required to be 2 inches off the surface, the congruent mass the chair must hold is 3000 kg. Ms. Bear, who has a mass of 2650 kg and is 7 inches in height, Figure 2, was developed for the students to conceptualize the mass their chair must hold. The construction also provided a discussion on materials, density, and body mass ratios.

A mini module was designed for students to understand structure strength. The students construct a triangle, square, and arch out of paper and test piling small area weights on top of each structure and compare the strength and deformation. Students then build cylinders in the shape of a triangle, circle and square and do the same experiment this time with books. This provides the students with a sense of shape to structure relationship. While the triangle is the strongest shape it lacks area. While a square supplies area it lacks strength. A single paper cylinder can hold upwards of 8 to 10 books depending on the type of paper. This allows the students to see that with the correct structure their chair will be capable of succeeding in building a chair to hold Ms. Bear.

The students begin with brainstorming, discussing and sketching ideas within their groups. With producing many ideas from their brainstorming, the students choose one and construct a prototype. Their prototype can only use up to 15 sheets of 20 lb. paper and hold $1/10^{\text{th}}$ of the final mass, 300 kg, without deformation. Each group goes through a testing period where a discussion is had to provide feedback on their models. This is an important step in the design process because like art, engineering is never finished and can always be improved upon. After testing, the students dive back into the design process of improving their work and prepare to build their final working models. The working models may use up to 15 pages of paper, either 20 or 80 lb. paper or a combination of the two. In between the testing of the prototype and building of the working model, the students are given another brief lecture on structure strength. A discussion of mass vs. weight is had to provide understanding of force and pressure. The students are introduced to the terms Young's Modulus, E, and the area moment of inertia, I, through the beam strength equation:

$$F = \frac{\pi^2 EI}{(Kl)^2} \tag{1}$$

where F is the force acting on the beam, K is the length factor of the beam, which is dependent on whether the ends are attached or free, and l is the length of the beam. By the end of the discussion, students understand that the force acting on their chair is Ms. Bear, which is approximately 29.4 N. Before a group is allowed to evaluate their chair, a calculation must be provided on the value of force the chair can withstand.

Fig. 2. Left: Ms. Bear in Student's Chair, Right: Student's Chair with Art Work and Crown

C. Renewable Energy

In this section of the curriculum, the focus shifts to energy awareness and uses the know, want to know, and learned, KWL, chart method [19]. The module focuses on the current energy-usage situation and current active methods of energy harvesting including renewable and non-renewable energy sources. The class holds a discussion about what they know about energy, what it is and where it comes from. Their answers go in the "K"now column of the KWL chart. Then ask them what they would like to learn about energy. These questions go into the "W"ant column of the chart. Following these discussions, the students are introduced to the six types of renewable energy: solar, wind, hydro/ocean wave, geothermal, biomass, and biofuel. This is completed through a creative coloring book and classroom games such as Family Feud, The Price is Right, and Jeopardy, which have all been adopted and placed in classroom settings previously [20], [21]. Afterwards the KWL chart becomes completed with filling in the last column, "L"earned. This particular curriculum was developed for L.E.A.P. (Localized Energy Awareness Program), which focuses on energy awareness in K-12 in a localized practice of making a difference through engineering [14].

D. Renewable Energy Origami Structure

Thus far the students have gained an engineering mindset with thought provoking questions, reverse engineering, and the engineering design process. With the addition of understanding what is happening in the world on the forefront of energy, the students are well prepared to combine engineering, origami, and renewable energy to develop a renewable energy origami structure. Origami in engineering and especially in architecture is a relevant and cutting edge field [22]. It allows for more complex designs with better understanding of kinetic behavior of structures [9]. The project design criteria states that the students' origami structure or building must utilize one of the six main renewable energies and serve a purpose in society other than to produce energy, i.e. home or business. The first step in this process is to break the students up into groups and assign each group a location around the world that their structure will be built. This provides the group with a specific design criteria to choosing their renewable energy source. For example, if their location was Oklahoma, U.S. or Barrow Island, Australia, once the students did research, both of these places are in the top five windiest places on earth. If their location was Arizona, U.S. or Asswan, Egypt, the students would find that these places are the sunniest places on earth, recording the most amount of sun shine. This design aspect of the curriculum allows teachers to explore the world and never give the same location twice.

Once the students have brainstormed and developed ideas for their structure, they construct prototypes out of paper. Then each group presents their research, findings, and ideas to a neighboring group. The groups provide feedback to then develop working model drawings: front, top, left and isometric. This allows the students to 3D render and print their structures.

Students accomplish this task using the technology of Tinker, an online open source CAD and 3D printing program.

III. Preliminary Results

Preliminary results have been taken from integration into the two geometry classes, N = 46, through pre surveys, exit passes, and post surveys. Provided with rubrics, the students were graded on all of the modules. These surveys and grades are presented here in tabular form followed by an analysis. Due to the fact that this is a work in progress and the curriculum is still being conducted and analyzed, the preliminary results only reflect up to the Origami Chair project.

Student interest, measured by end of class surveys, is displayed in Table I for each cohort and module. The results are overwhelmingly positive with an average of 97%. The interest in the module drops with the origami chair project to 89%. This could be due to the more demanding level of science and math integration into the curriculum. With previous studies by the authors and various other publications, it is known that student interest leads to a higher understanding and retention of a topic [13].

TABLE I
Student Interest

Module	Cohort A	Cohort B
Think Like an Engineer	100%	100%
Reverse Engineering	100%	100%
Origami Chair	92%	86%

For each module, students were evaluated on what subjects they believed they used during that time period. The results are displayed in Table II for each of the five STEAM subjects. The bolded values were the subjects distinctly used in each module. The students were always encouraged to utilize their laptops and other available technology in and out of the classroom for research during all of the modules, but because the students were working in groups, the average of 56% seems appropriate. While it could be argued that science was used in all three modules, the most apparent was in the origami chair project, where there is an introduction to physics principles. These results suggest students know what engineering is, as well as the other STEAM subjects individually.

TABLE II
STEAM Understanding by Students

Module	Science	Tech	Engr	Art	Math
Think Like an Engineer	37.9%	55.2%	62.1%	**68.9%**	**96.5%**
Reverse Engineering	26.7%	56.7%	**93.3%**	**93.3%**	**86.7%**
Origami Chair	**83.3%**	58.3%	**100%**	**75.1%**	**87.5%**

To assess the curriculum execution, making sure the key objectives of the module had been accomplished, surveys asked the students to list something he or she learned during the class period. Table III shows the percentage breakdown of students in each cohort that listed an answer that related back to the main point of the curriculum. As Think Like an Engineer had three parts to the day, the lower average percentage, 54%, is understandable. Their fellow was introduced during that class period, they did the pre-survey evaluations, and then the worksheet questions. In the future, these tasks should be broken down into multiple days. There is a slight increase in the Reverse Engineering Origami module, 58.5%. Finally, the Origami Chair Project had a high percentage of execution, 94.5%. This could be a combination of events. For example, with time the teaching fellow begins to have an understanding how the students learn best with walking through examples and sticking to one topic in a time period.

TABLE III
Curriculum Execution

Module	Cohort A	Cohort B
Think Like an Engineer	48%	60%
Reverse Engineering	63%	54%
Origami Chair	96%	93%

In post surveys, 92% of students said that this project thus far has made them more interested in engineering. The presentations and peer interactions has 96% of students feeling more confident in their presentation skills. Many students have provided optional feedback stating how the hands-on origami work is ”fun” and they feel it is ”approachable” and ”non-threatening,” which allows them to explore engineering with more of an open mind.

IV. Discussion and Future Work

The result of this work is an innovative practice and collaboration to help prepare students in STEAM through a better understanding of engineering and how it is applied in the world. Through the development of modules, the students are exposed to reverse engineering, the engineering design process, origami-geometric principles, non-renewable and renewable energy methods, and 3D rendering and printing. These modules are formed through the common core standards, the NAE Grand Challenges, and the NGSS practices for engineering and science.

The preliminary results show that the curriculum holds interest, understanding, and execution with positive outcomes from surveys. Cohorts A and B allow us to see that the increase in class size does not effect the outcome of the curriculum for 32 and 14 students, respectively.

Through the art of origami, students can be introduced to engineering concepts, while providing them with a better understanding of spatial relationships in geometry. This has a positive effect on their spatial thinking and cognitive skills. It doesn't take a large amount of class time, but brings excitement and knowledge around the topic of energy as well. This is important with the energy crisis in the world. As seen in American Association for the Advancement of Science, AAAS, Project 2061 Atlas of Science Literacy, students need an education on energy and the influence it holds in their daily life styles [18].

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