STEM Explore, Discover, Apply – Elective Courses that Use the Engineering Design Process to Foster Excitement for STEM in Middle School Students

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Abstract—Engaging students early in meaningful STEM experiences will help them maintain a level of interest in STEM fields later in life. However, the key is developing meaningful courses in STEM for K-12 students. These students not only need to have a “fun” experience, but a meaningful one, where they connect with, and develop deep understanding of the material being presented.

STEM Explore, Discover, Apply (STEM EDA) is being created by the Cyber Innovation Center, a 501c not-for-profit as a middle school elective course. STEM EDA is designed as a three course progression through topics that foster excitement for STEM. The curriculum is designed to enhance the core science and math classes taken in middle school. STEM EDA begins by exploring STEM concepts (STEM Explore, 6th grade) then transition to discovering fundamental concepts (STEM Discover, 7th grade), followed by the application of the concepts (STEM Apply, 8th grade).

This work in progress will outline the framework for STEM EDA, including the various modules of the courses. Additionally, this paper will discuss how the engineering design process is integrated into the modules, how other disciplines are highlighted, and showcase a specific module in this innovative middle school elective curriculum.

Keywords—Middle School; Engineering Design Process; curriculum

I. INTRODUCTION

Research has shown that engaging students with valuable STEM experiences early can help students maintain their interest in STEM later in life [1]. Introducing middle school students to STEM topics in a meaningful manner can increase their likelihood of staying engaged with STEM in high school and college [1]. Thus, there is a need for creating worthwhile STEM experiences for middle school students. This is evident by the national common core initiative. The common core standards for mathematics include incorporating lessons learned from previous classes to build on the students’ knowledge [2]. Additionally, the Next Generation Science Standards (NGSS) outline the need for engineering to be included in K-12 classrooms [3]. Incorporating engineering principles early can build the students’ problem solving and critical thinking skills as well as provide real applications to problems that students normally see as abstract [1]. Additionally, NGSS discusses the need for incorporating multiple disciplines in classrooms [3]. By learning through a multi-disciplinary lens, students can make connections throughout their classes and the world around them, rather than looking at each course as a discrete subject [4]. Incorporating these aspects in the middle school classroom can provide the meaningful experience needed to maintain student interest in STEM later in life.

A difficulty, though, is creating that meaningful STEM experience; this is no easy task. Project-based learning, a popular pedagogical style, is typically employed in order to engage students. This pedagogy has been shown to be beneficial [5]. However, in many cases that pedagogy is abused; and so often, the intent of “project-based” is lost. Rather than using the projects to enhance the course and drive to the fundamental topics, the projects become the main focus and the fundamentals are neglected. This is not to say that the project-based learning should no longer be used in classrooms, but it should be used in that manner by which it is intended. A more “project-driven” approach should be employed, where the fundamental topics are the main focus and the projects are used to enhance the curriculum, engage the students, and most importantly “drive” to the fundamental concepts.

In order to address this issue on the middle school level, the Cyber Innovation Center was asked to create elective STEM courses for 6th, 7th, and 8th grades. In order to develop these courses, the curriculum designers decided to use “classic” science projects, while leveraging the engineering design process to provide continuity, depth, and meaning to curriculum. Additionally, liberal arts context for each project will be included to provide deeper meaning to the projects as well help students make connections to the world around them, physically, culturally, and ethically. Thus the curriculum designers are developing STEM Explore,
Discover, Apply (6th, 7th, 8th, respectively) using these characteristics.

II. FRAMEWORK OF COURSES

The curriculum is being designed using a modular approach to each of the courses. STEM Explore, Discover, and Apply (STEM EDA) will capitalize on the “classic” science projects (e.g. the egg drop, volcano, catapult, bottle rockets) to drive to fundamental STEM topics as well as cultural and society applications. In order to provide continuity, depth, and meaning, within the various modules the curricula will leverage the engineering design process. The modules will incorporate a social studies, historical, and/or societal context to provide intellectual applications to the projects. Each level of the course will use the same themed project (e.g., module 1 is an egg drop for all grades), but will have different context and parameters, such that students will be doing completely different projects in each course. Additionally, the level of the fundamental concepts will increase gradually with each grade of the curriculum. Table I outlines the projected modules for each course in STEM EDA.

<table>
<thead>
<tr>
<th>Weeks</th>
<th>Module</th>
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<tbody>
<tr>
<td>1 – 3</td>
<td>Egg Drop (Engineering Design Process)</td>
</tr>
<tr>
<td>4 – 6</td>
<td>Volcanoes</td>
</tr>
<tr>
<td>7 – 9</td>
<td>Musical Instruments</td>
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<tr>
<td>10 – 12</td>
<td>Catapults/Trebuchets</td>
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<tr>
<td>13 – 15</td>
<td>Electricity</td>
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<tr>
<td>16 – 18</td>
<td>Solar Ovens</td>
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<tr>
<td>19 – 21</td>
<td>Trusses</td>
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<tr>
<td>22 – 24</td>
<td>Boats</td>
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<tr>
<td>25 – 27</td>
<td>Bottle Rockets</td>
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<tr>
<td>28 – 30</td>
<td>Earthquakes</td>
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<tr>
<td>31 – 33</td>
<td>Racecars</td>
</tr>
<tr>
<td>34 – 36</td>
<td>Roller Coasters</td>
</tr>
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</table>

Each module will span approximately three weeks. The students will follow the steps in Figure 1 throughout each three-week module. Students will be guided through each step by the instructor, while building their own inclination for the process.

In Step 1, students will learn how to interpret information and write a concise, but informative problem statement. In Step 2, student will learn to interpret information from articles. Step 2 will be a large focus of the modules, allotting for many of days in the three week module. Students will be given, and when appropriate find for themselves, applicable articles. Students will be challenged to read the articles and extract pertinent information. Students will have open discussions and sharing opportunities which will drive the learning of the fundamental content. During Step 3, students will learn to plan ahead. They will think of various solutions to the problem and organize their ideas accordingly. For Step 4, students will use their critical thinking skills and the information they learned in Step 2 to choose the best solution to the problem. After they have chosen the solution, they will begin to build the prototype of their design in Step 5. This will put their construction skills to the test as well as help them realize how something they design on paper and in their minds can be built in the physical world. Once the prototype is built, the students will move to Step 6 Test and Evaluate the Prototype. This is an essential step; students will see if what they built performs in the manner they intended. Finally, after testing and evaluating the prototype the student will reflect on the design and determine ways they can improve upon their design, Step 7.

In addition to the engineering design process steps, the students will learn the overarching themes of the process: iteration, communication, imagination, and creativity. Students will learn that design is never completed and the process is based on iteration so that improvements can be made. Throughout the modules, students will be challenged to maintain communication with not only their teammate, but the instructor and other classmates as well. Heavy emphasis will be placed on imagination and creativity such that students are able to express themselves through the projects.

With each module, students are tasked with developing a creative story element related to the context and their design. Including the creative writing assignments will help the students develop their writing skills, while also helping them think through the context of the module and how their design applies to the context. Additionally, the creative writing assignment adds another layer of depth to the curriculum such that students are applying elements from other classes, like English, to a STEM course.

III. EXAMPLE MODULE

The egg drop module will be first for each level of the curriculum. This project is based on the classic, “create a vessel to protect an egg from breaking as it falls from a specified height.” Typically this project is completed over a two day time span, with one day for building a vessel. The next day, students drop the vessel hoping that the egg will not break. When done in this manner, often the fundamentals are overlooked, and the activity itself takes the main focus. However,
in STEM EDA, because of the engineering design process, time will be allotted to the research component. Therefore, the fundamentals concepts will be at the forefront. Additionally, since the egg drop is the first module of the curriculum, it will serve as the vehicle to frame the importance of the engineering design process. In STEM EDA, students will complete the egg drop module in the typical manner first, where they will build a vessel with little to no research or discussion on the fundamentals. The following day the students will drop the vessels. Many students will fail; this is okay because now the teacher has an opening to discuss why the vessel may not have performed as planned. This will be a natural lead into the engineering design process, where students will redo the project; this time, however, using the engineering design process as a guide. In each course, heavy emphasis will be placed on open discussion, where students will be asked to share their thoughts and designs with the class throughout the engineering design process.

A. Explore (6th grade)

The context for the Explore egg drop module is based on a stuntman jumping from a building. Students will be required to use only a select amount of materials such as cotton balls, Styrofoam cup, Styrofoam bowl, straws, limited amount of tape, and twine to build their vessel. Through the research process students will learn the concepts of gravity, force, velocity, acceleration, Newton’s second law of motion, center of gravity, and mass versus weight. Prior to dropping the vessels students will have to calculate the force at which the vessel will hit the ground, and during the drop, students will determine the average velocity of their falling vessels. After constructing the prototype vessel, students will have to write a creative story on why the stuntman is jumping and how their vessel will keep a stuntman safe as he jumps out of a building.

B. Discover (7th grade)

The context for the Discover egg drop module is based on a skydiver jumping from a plane. Students will only be given straws, tape and a garbage bag to construct their vessels. Through the research component, students will learn about gravity, velocity, acceleration, law of conservation of energy, kinetic energy, potential energy, air resistance, and parachutes. Students will have to calculate the potential energy for their vessel. During the drop they will have to find the velocity of their falling vessels to determine the kinetic energy. Knowing the law of conservation, students will make the connection that energy was dissipated elsewhere since the kinetic and potential energy will not equal each other due to the parachute. They will then determine the amount of energy dissipated due to air resistance. Also, students will be tasked with writing a story about the skydiver and how their design will keep him/her safe.

C. Apply (8th grade)

The context for the Apply egg drop module is based on dropping supplies to refugees in a foreign country. Students will be able to use various items like straws, tape, garbage bags, cotton balls, Styrofoam cups, Styrofoam bowls, and twine to construct their vessels. However an added element to the Apply lesson is the consideration of cost efficiency. Students will be given a budget, and must purchase the items for their vessels within the budget. The size of the vessel will also have a cost associated with it. The larger the vessel the more money the students will have to spend. Students will have to research the same concepts as Discover, as well as calculate potential/kinetic energy and drag. However, in addition to these concepts, the students will have to find articles of supplies being dropped to refugees in a foreign country. They will then use this information to write their creative story on the vessel design. Students will have to choose refugees from one of their articles, and incorporate factual information about them as they write their story from the view point from the pilot dropping the supplies.

IV. Conclusion

Currently two modules, the egg drop and volcanoes, have been created for all three levels of the curriculum, Explore, Discover, and Apply. The egg drop, which is used as the vehicle to demonstrate the necessity of the engineering design process, is being piloted at a local middle school. For the Fall 2013 school year, three to four middle schools will be piloting the curriculum. The designers intend to have five to six modules fully developed for the beginning of the school year. As the first semester concludes, the designers aim to have the remaining six to seven modules completed.

REFERENCES


