Assessing the First-Year Pilot of STEM: Explore, Discover, Apply – STEM Curricula for Middle Schools (Work in Progress)

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Abstract

Improving the quality of science, technology, engineering, and mathematics (STEM) programs in K-12 schools is a nationwide initiative. School administrators and teachers are experimenting with innovative curricula that will engage students in STEM subjects. However, teachers and administrators are cautious about employing new techniques due to concerns like time limitations on lessons, the plethora of content required to be covered during the school year, and resource restraints. Therefore, it is critical that any new curricula be beneficial to all involved parties: school administration, teachers, and students. The new curricula must reach the goal of the aforementioned initiative – to improve the quality of STEM education.

In order to answer the initiative, the National Integrated Cyber Education Research Center (NICERC) curriculum development specialists created middle school elective curricula for grades 6^{th}, 7^{th}, and 8^{th}. The curricula use science and design projects framed by the engineering design process to engage students. The content is presented in a modularly, increasing in difficulty through the grade levels. Each module consists of a design project lasting approximately three weeks if presented in a singular class one hour in length.

This work in progress assesses the first year implementation of NICERC's STEM: Explore, Discover, Apply (STEM EDA) curricula at three diverse K-12 schools. Through the pilot schools, the versatility of the curricula is showcased. The curricula are being piloted by a public, charter, and private school, all of which are conducting the courses in different manners. The public school implements the curricula as a standalone elective course. The charter school presents each module over one-week periods, where a cohort of teachers integrates the content throughout multiple classes. The private school chooses specific modules that are applicable to lessons in its current science curricula and presents those lessons using STEM EDA modules. Teacher and student feedback provides the data that will be the basis of the assessment. By taking the feedback into consideration, the successes, failures, and future directions of the curricula are evaluated and presented in this work-in-progress paper.

Introduction

In the report "Rising Above the Gathering Storm," written jointly by the National Academy of Science, National Academy of Engineering, and the Institute of Medicine, taking action to improve the quality of K-12 education in science and mathematics is identified to be essential for enhancing the nation's future. One of the main actions the National Academies identified as a method to enhance K-12 education is "increasing the number of students who take AP and IB science and mathematics courses." They note that creating advanced work for not only high school but also middle school can help in this initiative. Additionally, using interactive pedagogies such as inquiry based learning will provide students with meaningful experiences that showcase the importance and satisfaction of pursuing careers in STEM[1].

Research has shown that students as early as middle school develop an affinity or aversion to STEM[2,3]. In one study, it was found that "life experiences before 8th grade may have impact on future career plans." The researchers further conclude that in order "to attract students into the sciences and engineering, we should pay close attention to children's early exposure to science at the middle and even younger grades[4]." Through this research, as well as the initiative set forth by the National Academies, one can conclude that a focus on the middle school years is crucial to help excite and encourage students to pursue STEM pathways. This conclusion is one of the first steps in overcoming a national dilemma. However, it is important to keep in mind programs created for middle school students should not only be exciting but also meaningful where the students learn the core STEM concepts. It is the meaningful experience, not the "fun" experience, that keeps students engaged with STEM later in life[2].

Incorporating engineering in the K-12 classroom has been found to provide students with meaningful applications and connections to content which students might not have otherwise made. Engineering exposure at the middle grades can build critical thinking and problem solving skills, and it can also help students connect to ideas that they would normally see as abstract. One study further concludes that "demonstrating how engineers and scientists use mathematics to solve real world problems would encourage students to continue their math and science studies[5]." State and national committees have taken note of the benefits of incorporating engineering in the K-12 classroom. Many new standards have included engineering applications in the requirements for science curricula. Most notably, the Next Generation Science Standards (NGSS), which are being adopted by many states, outline engineering principles and applications with K-12 science classes. NGSS showcases the importance of engineering in the K-12 classroom as well as differentiating and identifying connections between engineering and science[6]. Massachusetts, Georgia, Texas, California, and Minnesota are a few of the states that have explicit engineering standards while many other states have some form of engineering or design standards[7]. Teachers who have been exposed and trained in incorporating engineering with their mathematics and science classes have realized the meaning and enrichment that engineering brings to their teaching in addition to the students' experience[8].

In addition to bringing engineering applications to K-12, research has shown that providing students with inter-disciplinary curricula helps them make connections and maintain engagement with content. NGSS and Common Core State Standards (CCSS) indicate the need for connections to be made between subjects as well as previously taught content[6,9]. An article entitled "Interdisciplinary Learning: Process and Outcomes" provides support to the idea that students who learn concepts that are presented using a multi-disciplinary approach will, rather than view each subject discretely, make better connections with concepts throughout all their classes[10].

Taking these and other studies into consideration, NICERC developed STEM: Explore, Discover, Apply (STEM EDA) a three part middle school curricula for 6th, 7th, and 8th grades. The courses provide schools with a versatile solution to providing middle students with meaningful interdisciplinary curricula that incorporates principles of engineering. This work-in-progress will address the curricula's implementation at three pilot schools by assessing preliminary data gathered from teachers and students.

Summary of STEM EDA Curricula

Figure 1. Engineering Design Process Graphic

STEM Explore Discover Apply provides middle schools with three courses: STEM Explore (6th), STEM Discover (7th), and STEM Apply (8th). These courses are designed to foster excitement for STEM concepts by providing a meaningful experience for students. STEM EDA uses the engineering design process (Figure 1) to guide middle school students through classic science and design projects. The engineering design process (EDP) adds a level of robustness to projects that may be perceived as overdone or not impactful. The curricula are designed using a modular approach such that each module lasts approximately three weeks in the classroom environment. A version for each module is developed for each grade level. For instance, there is an Explore, Discover, and Apply version of the first module, Egg Drop. This module, while emphasizing classic STEM concepts related to an egg drop, also introduces the engineering design process to the students and how the engineering design process will guide them through subsequent modules. In addition to using the engineering design process to enhance the project disciplines outside of STEM, English, social studies, and history components are incorporated to provide context and more meaning to the modules.

Table 1. List of current and future modules developed for STEM EDA

STEM EDA Module
Egg Drop (Introduction to Engineering Design Process)
Volcanoes
Roller Coasters
Catapults
Genetics
Electricity
Music
Earthquakes
Bridges
Boats
Solar Ovens
Bacteria
Systems of the Body
Racecars

Table 1 outlines the current modules as well as future modules intended to be developed. A goal of the curricula is to have multiple modules such that schools can choose among the bank of modules to implement with their students. The modules in blue have been developed, and the modules in orange will be developed by August 2014. Additional modules to be developed after August 2014 are highlighted in green. Note that each of these modules has an Explore, Discover, and Apply version where the context and materials being used changes, and the STEM content progresses with each grade level as appropriate. Although the basic idea of the modules are similar, like a catapult or egg drop, they differ through the levels by context, materials used, and degree of fundamental content. Appendix A showcases an outline for the STEM: Explore, Discover, Apply catapult modules as an example of the STEM EDA curricula**.**

First Year Pilot

STEM EDA was initially designed as elective middle school curricula to foster excitement for STEM concepts by providing a meaningful experience for students. Three regional schools, a charter, private, and public school were chosen to participate in the first year pilot. The schools were strategically selected to determine the curricula's ability to be implemented in different types of schools. In summer 2013, prior to the school year, a weeklong immersive professional development workshop was held for the teachers implementing STEM EDA. The curricula developers guided the teachers through four modules to help familiarize them with the engineering design process. By the end of the week, teachers developed the confidence to implement the modules and use the engineering design process as the backbone for instruction. Additionally, the teachers were able to develop a relationship with the curricula designers and other teachers implementing the curricula, which provided a network of support going into the school year.

After the professional development workshop it became clear that each of the schools would conduct the course differently. Allowing the schools to implement STEM EDA in various ways provided an opportunity to assess the versatility of the course. Through each of the three pilot schools, a total of 347 students are participating in the STEM EDA curricula.

Public School – The public school had the ability to create a new elective course for their 6^{th} and 7^{th} grade students. The school chose to divide the course into two parts: STEM EDA and robotics. Because of the curricula's modular design, the school was able to choose 7 modules (Egg Drop, Volcanoes, Roller Coasters, Catapults, Genetics, Electricity, and Music) to implement while also intertwining three robotics modules within the class. The robotics modules that were incorporated into the class helped the students prepare for a regional robotics competition held by NICERC. The public school has 29 students in the Explore class and 14 students in the Discover class.

Private School – The private school did not have the flexibility within its curriculum to implement a completely new course. Therefore, the teachers chose specific modules that aligned with the content in current science curricula for 6^{th}, 7^{th}, and 8^{th} grades and inserted them within the course where appropriate. The private school has 38, 32, and 26, students in the Explore, Discover, and Apply classes, respectively.

Charter School – The charter school, like the private school, did not have room in its school day to add another course. Instead, the 6^{th} and 7^{th} grade teachers worked together to identify the areas in which the modules could be taught in multiple classes. For instance, the math sections were taught in math classes writing sections were taught in English class, and the science concepts were presented in the science class. This allowed for each module to be presented in approximately a week. The 6th and 7th grade classes implemented five modules: Egg Drop, Volcanoes, Roller Coasters, Genetics, and Catapults. The 8th grade classes implemented modules through their science classes, much like the private school, to provide more time and opportunity for other students to participate in the modules. The 8th grade modules were also presented as an after school program. The charter school has 78, 78, and 52 students in Explore, Discover, and Apply, respectively.

Preliminary Analysis of the First-Year Pilot

Throughout the first year pilot, feedback was provided by teachers and students to help assess the positive and negative aspects of the different implementations. The feedback from teachers has been encouraging. Specifically, teachers have, unprompted, mentioned areas where the curricula meets the goals set forth by the curricula developers. For instance, an initial goal of the courses is to foster excitement in STEM and encourage students to pursue a career in a STEM discipline. Two teachers relayed the following in accordance with that goal:

> *"I am [sic] truly enjoyed this journey of piloting the STEM EDA program in our school. I am overjoyed with the confidence that I see in our students. Where they once thought that they could not be successful with a STEM program, they are flourishing! Students are starting to look towards the future and truly believe that they could pursue a career in a STEM related field; this was not even a consideration before!"*

> *"There is an energy here that is very contagious. My 6th and 7th graders are motivated, excited, and anxious to come to school and work on this module. They have been inspired to do independent research and testing. Students who were unmotivated and uninvolved are now key players in their small groups and have found an interest in academics they didn't think they had."*

In respect to the implementation of the modules, teachers have provided the following feedback:

> *"I also like the "Cool" factor for each of the modules. The kids think that the tasks are just awesome, and they are engaged throughout the entire 3 weeks."*

> *"I think that providing a correlation and aligning each module with the NGSS or GLES would be great. And also to provide rubrics for the projects that teachers could adjust for their classes."*

> *"My kids are very disappointed when they do not have a booklet- they really like their "engineering books". They were so disappointed when they didn't have a booklet for the genetics module that I copied the booklets for them, and tried to hold them together with a ring- it didn't work very well."*

> *"Maybe include video links, possibly a thumb drive including teacher tools, links, pics, PowerPoint, etc. [for teachers]"*

The positive responses from teachers about STEM EDA are encouraging for future iterations of the curricula. The implementation feedback provided by the teachers will prove helpful in creating the second-year implementation. Knowing what worked and what did not work provides an insight that can be relayed to future teachers of the course as well insight for the developers as they create new modules.

The students were given three open ended questions. First, after completing the initial egg drop module, the students were asked to provide general feedback about their experience. The feedback proved to be overwhelmingly favorable. Out of 36 responses, 28 were completely positive, and Table 2 highlights these specific aspects the students mentioned. Eight responses were also positive, but included constructive suggestions for improvement on the areas of brainstorming, research, time constraints, and more activities.

Table 2. Aspects students felt were positive in the STEM EDA module

Positive Aspects	Number of comments mentioning aspect
Engineering Design Process	11
Being and Engineer	4
Imagination/Creativity	4
Teamwork	4
Liberal Arts	3
STEM	3

The second and third open ended questions were complimentary in that one asked what the students liked most (Q2) and the other what they disliked most (Q3) about the STEM EDA modules. For Q2, 51 responses were collected and 49 responses were collected for Q3. The feedback from both questions were categorized and input into pie charts, Figure 2 and 3.

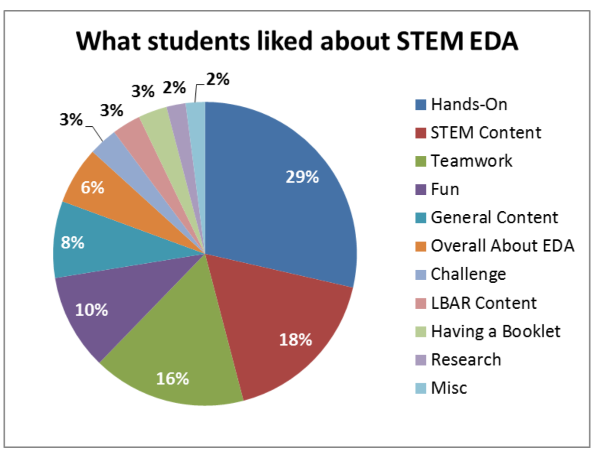

Figure 2. What percentage of areas students liked about STEM EDA, Q2.

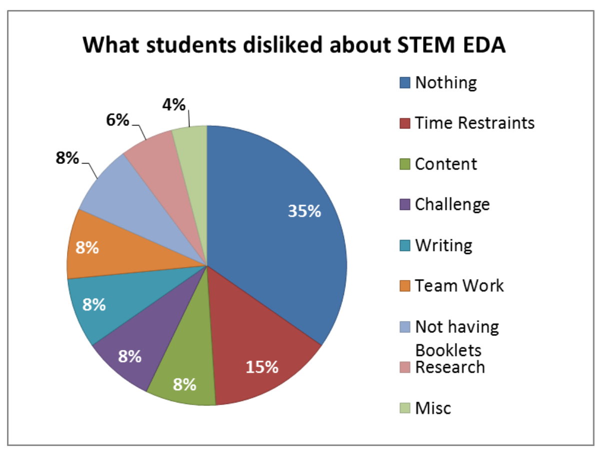

Figure 3. What percentage of areas students disliked about STEM EDA, Q3.

When looking at Figure 2, the main area that students liked was the hands-on activities of the curricula followed by STEM content and teamwork. It is interesting to note that "fun" showed up as the fourth most liked category. It might be assumed that students in middle school would put higher priority on "fun" over other areas. However, this feedback shows that although the students did have fun with the curricula, most liked other aspects greater. It should be noted that each category may not be mutually exclusive.

Figure 3 outlines the areas that the students disliked with the greatest area being "nothing." This reflects positively on the curricula. The second highest area the students disliked was time restraints. This may not necessarily be a reflection of the curricula, but rather, restriction of the school and how they are implementing the modules.

Conclusions and Future Plans

As the first-year pilot concludes, further analysis can be conducted on the feedback to draw formal conclusion on the success and failures of the course. As of now, only inferences and no full conclusions can be made based on the preliminary data. To date, one can infer that the course has been successful at this point and has attained the goals set forth by the curricula developers.

Throughout the remainder of the school year, data will continue to be collected in the form of a survey with open ended questions. Additionally, questions where students rate specific aspects using a Likert scale will be implemented. Analysis will also be performed on feedback collected from both teachers and students on how the various methods of implementing the curricula affected the curricular experience. This feedback will be useful for curricula design and improvement decisions being made for the second year pilot.

For the 2014 school year, STEM EDA will expand to districts outside the initial region and will be conducted in at least 10-15 different schools. All teachers will be required to attend the professional development workshop in the summer prior to the school year. Data will continue to be acquired for further analysis on the curricula.

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Appendix A: Curricula Example

An example of the STEM: Explore, Discover, Apply catapult modules are outlined in Table 3. Notice each module started with some form of catapult, but each module is vastly different.

Table 3. Example of Explore, Discover, and Apply catapult module.

Module: Catapult			
Step in EDP	**Explore**	**Discover**	**Apply**
1 Identify the Problem	Students' electronic devices have been taken away. They have to build a real life version of the game that used a sling shot to knock down blocks.	Because the school mascot is the medieval knights, students build trebuchets to throw prizes into the crowd at pep rallies and sporting events.	Students are designers for an outdoor game company and they have to build a game using a mangonel type catapult for a new outdoor game.
2 Research the Problem	Research/learn about sling shots in history; trajectory; projectile motion; parabolas; components of sling shots; tension; and surface area.	Research three main areas: history of trebuchets; Middle Ages; and components of trebuchets (base, supports, lever, fulcrum, counterweight, and sling).	Research/ learn about catapults in history; types of catapults; components of mangonel catapults; trajectory; spring constant linear equations; best fit lines; and potential energy.
3 Brainstorm Solutions	Develop at least three ideas for each component: base, supports, and tension mechanism.	Develop three ideas broken down by base, support, lever/fulcrum, counter weight, sling, and overall design.	Develop three ideas that include considerations for base/supports, lever/bucket, fulcrum, and spring.
4 Choose a Solution	Analyze combinations of ideas; rate them on ease of construction, tension mechanism, functionality, and use of materials.	Assess/rate each design on base, supports, lever/fulcrum, sling, counter weight, use of materials, ease of construction, function and performance, and uniqueness of design.	Assess/rate each design idea on ease of construction, functionality, fulcrum design, and use of material.
5 Create & Develop a Prototype	Build prototype of design chosen in step 4.	Build a prototype for the design chosen in Step 4.	Build a prototype for the design chosen in Step 4.
Creative Writing Activity	Write a creative story about being trapped inside the game.	Research heraldry and create a coat of arms and motto to be included on your trebuchet.	Develop a marketing campaign for the game.
6 Test & Evaluate the Prototype	Develop an apparatus to measure vertical and horizontal pull back distance for consistency in launches. Launch projectiles to knock down blocks set at specific distances.	Create an aiming system based on counterweight mass and the amount the lever is pulled back; calculate P.E. for different masses and pull back amounts; calculate theoretical maximum range; and test launches of the trebuchet.	Calculate P.E.; analyze effect of spring displacement with projectile distance; effects of release angle; develop apparatus to predict travel distance; and test catapults with game rules.
7 Improve & Redesign	Evaluate sling shot performance and identify areas for improvement.	Calculate range efficiency. Discuss, determine, and make improvements.	Evaluate catapult performance and identify areas for improvement.