AC 2012-4711: IMPLEMENTING ENGINEERING-BASED LEARNING IN BOSTON ARTS ACADEMY HIGH SCHOOL STEM COURSES

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Implementing Engineering-Based Learning in Boston Arts Academy High School STEM courses

ABSTRACT

The Boston Arts Academy is a unique urban high school in that its curriculum is devoted to the intersection of arts and academics. Our school believes that art is essential to our students' learning, and it is necessary for us to integrate arts into our STEM courses. Our school curriculum is packed, so it is difficult for us to add new courses. Therefore, we needed to change our pedagogical approaches to find ways to connect theory to practice, which has resulted in our creation of STEAM (science, technology, engineering, arts, and math) as a guiding philosophy. We need to show our students the use of STEAM concepts in real-life applications.

In searching for a solution to change the way we teach high school students STEM courses, we found a new and unique program called CAPSULE offered by Northeastern University. The approach uses engineering-based learning (EBL). Thus, two teachers (one teaches chemistry and one teaches physics/math) from our school attended the Professional Development (PD), offered as part of an NSF grant. Unlike traditional pedagogical approaches such as the 4E and 5E models and the scientific method, the EBL pedagogical approach provides two benefits. First, it contextualizes the STEM concepts and makes the underlying mathematical or scientific principles more relevant to the student, and in doing so it generates challenges and excitement. It is our hypothesis that by adding EBL as an organizing principle to our STEM classes, this will lead to increased student achievement and interest in STEM education as measured by the number of students taking elective science and math classes and the number of students selecting STEM careers. Second, the EBL provides a general framework, skill set and tools that are applicable to any STEM subject or course. That is possible because EBL pedagogy uses the engineering design process (EDP) and the college-level known capstone experience.

The paper will cover the details of our implementations of EBL in our courses, the changes we have made, the obstacles we faced in integrating EBL into our chemistry and physics/math courses, the results, students' reactions and feedback, and what we have learned. We also present how we implemented our action plans we developed during the PD in our classrooms. One important lesson we have learned is to build capacity in the same high school, i.e. the more teachers who train and use the EBL methodology, the better and more effective the implementation and the support system are as teachers can bounce ideas off of each other.

Introduction

Founded in 1998, Boston Arts Academy (BAA) is the city's first and only high school for the visual and performing arts [1]. It was founded on the conviction that academics and the arts are equally important to student development and achievement. The arts are integrated throughout the academic curriculum motivating students with a variety of learning styles to succeed in high school and pursue higher education. BAA is committed to providing a rigorous arts and academic education to urban youth who seldom have the opportunity to focus on the arts.

Its 405 students reflect the diversity of the seventeen Boston neighborhoods from which they come: 49% are African American, 29% Latino, 17% Caucasian, 3% Asian, and 2% self-identified as Other. Nearly 60% come from low-income households. Because of its success with urban students, BAA is a recognized leader in public education reform movement. Its innovative use of the arts as a strategy for improving teaching and learning has attracted national and international attention. Through the school's Center for Arts in Education, BAA's best practices are documented and shared with educators, administrators and policymakers worldwide.

Students at BAA are required to take three years of science and four years of math in order to graduate. Typically, students take Engineering in the 9th grade, Chemistry in the 10th grade, and Biology in the 11th grade, with an elective course on Current Issues in Science in the 12th grade. In math, students typically take Geometry in the 9th grade, Algebra 2 in the 10th grade, and a Trigonometry/Statistics course in the 11th grade. Eighty percent of our students complete a Precalculus course in the 12th grade, though we have been trying to increase the number of students who complete this course despite inadequate funding.

Teaching STEM (science, technology, engineering, and math) to high school students is particularly challenging. Students lose motivation and desire to learn STEM subjects and/or take STEM courses as electives. In talking to students, we have discovered that this lack of interest among them is not an indication of deficient learning abilities but rather a result of inability to relate the abstract STEM concepts to the societal context of their surroundings. Students do not realize that what they learn, e.g. a chemical reaction in a chemistry class or force analysis in a physics class, apply to everyday products they use, be it running shoes, an iPod, or a cell phone. The question we wish to explore is will adding EDP (engineering design process) as an organizing principle in our STEM classes increase student achievement in STEM courses and cause more students to pursue STEM careers?

CAPSULE PD

NSF has funded a three-year strategies project titled "CAPSULE: CAPStone Unique Learning Experience." The goal of CAPSULE is to develop, implement, and evaluate an innovative Capstone project-based learning (also known as capstone experience) model for high school teachers and students. In speaking with teachers in local schools, we learned that students have difficulty staying motivated in STEM courses because they do not see the value of what they learn in chemistry or physics class. To address this issue, CAPSULE learning model uses the top-down project-based learning model to effectively convey to students the value of STEM/IT subjects. In this approach, students learn by doing; as they analyze and solve real-world problems they discover the connections between STEM concepts and real-world applications. This approach is different from the conventional bottom-up approach, in which students and teachers focus on basic principles, but most often fail to see connections to the big picture, and hence lose interest in learning.

The chemistry teacher has been teaching science for the last thirty-five years, and in these years he has seen a great deal of change in the world, the proliferation of technology and sophisticated scientific and Engineering advancement, yet the high school science curriculum remained essentially static; this despite the number of educational reform movements. With the advent of MCAS (high-stakes science exit exam) we realized that we needed to make substantial changes to the curriculum if BAA was to be successful [2, 3]. The initial change we made was to introduce a class on Engineering and Technology that all ninth grade students would take. We also made all ninth grade students take the MCAS Engineering test. PD was given to the staff by the Boston Museum of Science (Engineering the Future), the result was that BAA and their students did very well on the MCAS test, with a 92% pass rate. The Engineering curriculum was very project based, hands-on, and worked to solve real problems using scientific knowledge. This was the first time students actually saw value in the scientific principles being studied. This was a great epiphany for the teachers of BAA. While we were busy working on our Engineering and Technology course, the Skills for the 21st century were released and were being discussed among educational circles [4, 5]. Upon inspection of this document, the only class we were teaching that approached this ideal was our Engineering class. This began our quest for PD that would lead to upgrading our STEM classes.

The chemistry teacher decided to apply, in Summer 2010, to the CAPSULE Program because it was an Engineering focused approach to teaching STEM classes. The CAPSULE team provided a model that we were looking for that could be incorporated into our preexisting classes. What he captured from the Capstone experience is that Engineering and capstone projects provide students opportunities to use their knowledge and skills to develop solutions for problems. These opportunities to demonstrate understanding are too often missing from current curricula. At BAA we are re-engineering our STEM classes to provide students with the same opportunities to demonstrate knowledge and solve problems in novel and unique ways. While in the past our science activities basically were cookie-cutter activities, activities that often required nothing more than following instructions to perform, often with little understanding or engagement being needed to perform.

The math teacher attended this two-week professional development program during the summer of 2011. She found that the most valuable part of this experience was approaching engineering design process the same way one would expect their students to approach their projects. For example, the very first day of the program teachers worked in small groups to create a three-legged chair from all recyclable materials that had to meet certain criteria. In this way, teachers had the opportunity to use the engineering design process the same way their students would in class. Teachers also worked in groups on a week-long project that required teachers to build a bookcase using CAD software. Again, it was essential for teachers to experience the engineering design process the way their students would – trying to create a prototype as a solution to a problem using teamwork over a week-long period. In short, by creating projects for teachers to complete, the CAPSULE Program was helping teachers become better equipped to create projects in their own classrooms based on the engineering design process.

Implementation Plans

The experience with CAPSULE program and the opportunity to apply for a grant with Qatar Foundation International (QFI) to help redesign our science-math program has resulted in the formation of the STEAM team [6].

This year (2011) at BAA, our math and science teams have merged and become the STEAM team. Thanks to continued support from QFI, we are in our second year of a new initiative that we are calling "STEAM." This stands for "Science, Technology, Engineering, Arts and Math," and it reflects the idea that we are interested in creating learning experiences for students that blend these different disciplines together instead of teaching them as entirely separate subjects.

What has STEAM meant for students? Last year we were able to develop new projects for our students in both math and science. Math students learned about the geometry of tessellations and how these patterns are incorporated into Islamic and other tiling designs, learned to use new computer technology to create different forms of animation, and applied quadratic functions to physics in rocket launching project. Science students used a program called SAM animation to create stop-motion animated movies that describe mitosis, and contributed to the rocket launch project by combining pneumatics and construction to build the actual rocket launchers.

Beyond this work in the normal classes, the STEAM initiative allowed us to start an after-school robotics club and to expand the scope of the projects for Chemistry open honors students. If you visit youtube.com and search for "Boston Arts Academy STEAM," you can get a fuller picture of the different ways that we were STEAM-y last year.

This year, with our continued support from QFI, we have officially merged our math and science teams into one STEAM team, giving more time for teachers to communicate and plan across the curriculum. Our STEAM teachers have also been having conversations with our arts teachers to create even more integrated projects for our future.

One of our biggest changes this year has been creating a new Applied Math and Physics course that has a curriculum based upon major projects connecting all five areas of STEAM! The students in this class have explored the physics of music through glass bottles, displayed their understanding of Newton's Laws through SAM stop-motion animation, done a deeper exploration of the rocket launch, and much more. We hope this course is just the beginning of what will be many more places for students to combine their understanding of science, technology, engineering, arts, and math.

During the two-week CAPSULE professional development, the math teacher created an implementation plan for two of her classes to begin incorporating projects and the engineering design process into the current curriculum. One course is a basic algebra course where students are reinforcing their number sense and practicing their equation solving skills. The class already has several projects, including a budget and finance project where students must design their life in the "real world" and a fraction and decimal project where students must double a recipe and set prices for a bake sale. After experiencing the summer PD, The math teacher decided to add a project where students have to use their knowledge of probability and statistics to design and create a marketable board game. Here, students will be able to work in small groups using the engineering design process to create a prototype. The other course is a hybrid physics and advanced algebra course that was being taught for the first time. The math teacher decided to create several projects to be the basis of the course: a rocket project, a stop-motion animation project, an instrument-making project, and an egg drop project. With these four projects, students would be able to use the engineering design process to apply their knowledge and understanding of basic physics concepts.

Execution

One of the most important decisions our school made this last year was to combine our previously separate math and science teams into one STEAM team. This choice is a first step towards integrating science and math in our curriculum. The goal this year is for us to get to know each other's courses better so we can see where we overlap. The next step would be to see how we can make each other's courses stronger by creating a more comprehensive curriculum. Another goal is for us to investigate each other's projects to see where we can use the engineering design process better and help integrate more arts into our courses.

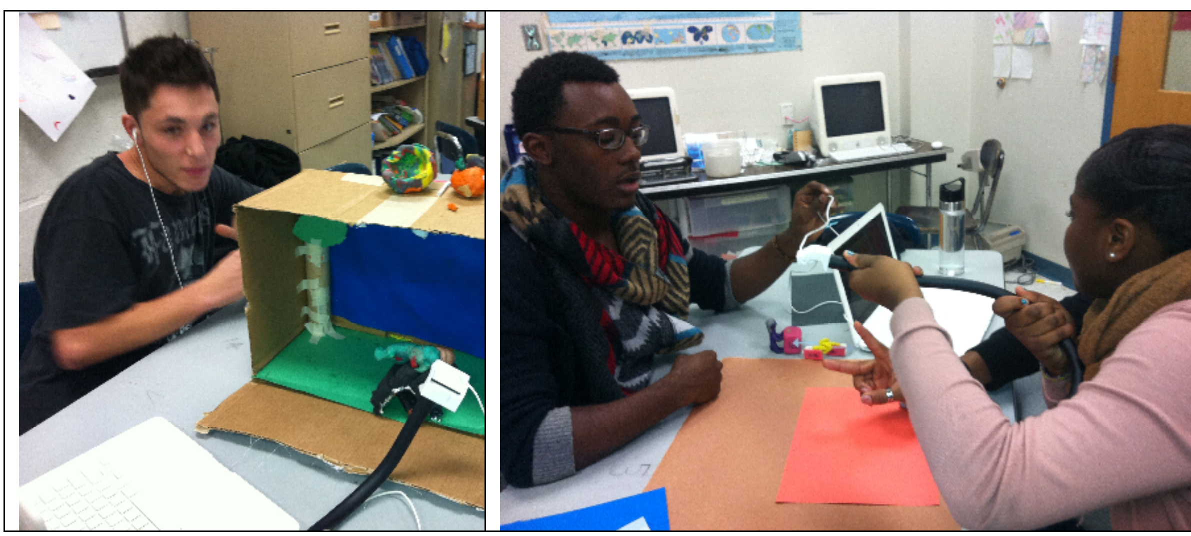
Chemistry/Engineering Chemistry Open Honors students completed a project that incorporated their knowledge of Chemistry and Engineering. The assignment was to create a prototype of a product that solved a problem or an object that combined art and science topics. Students came up with their own ideas, researched the chemistry behind their project, and planned and constructed a prototype. One group created a solar-powered filter that could be used in developing nations to filter particles and dirt from water. They researched how activated charcoal is used in filtering. Another group had the idea to create a "lava lamp wall" using an immiscible mixture of color-dyed benzyl alcohol and a salt solution. Their prototype consisted of an aquarium tank filled with the mixture on top of a base built from PVC pipes, form core, and a metal sheet. Light bulbs beneath the metal sheet acted as a heat source. This group explored how differing densities of the materials created the rise and fall of lava lamp "bubbles." A third group created biodiesel, a fuel made from vegetable oil that can be used in diesel engines.

The Rocket Project is a collaborative project between the math and science teams based upon a rocket unit from NASA educational materials. Ninth grade Engineering students used their knowledge of the Engineering Design Process and construction technologies to build rocket launchers using PVC and bike pumps. They learned how to use various tools in their construction and how to follow an instruction manual. After building the launchers, some students were able to test and evaluate their launchers. It also provided them with a real-life example of open-system pneumatic devise. Tenth grade Math students built paper rockets and using their knowledge of quadratic and linear equations, calculated the distance to place the launcher away from a target in order to hit the target with their rocket. Math students learned basic physics concepts involved in projectile motion and completed two rocket launches. This was an opportunity to see how engineers are commissioned by working scientist to create devises that help them understand important fundamental scientific concepts.

Students have been more successful in the newly created Physics & Algebra course. They have been more motivated to engage with challenging material by attacking a problem with a hands-on project. Because they are able to create their prototypes and physically see how the laws of physics are acting in the world, they are then more likely to understand the abstract algebra concepts that explain the physics. For example, it was much easier for students to use kinematics equations and interpret graphs when they got to see the motion happening. It was helpful for students to be able to create and see their rockets (Figure 1) travel in a parabolic trajectory because they were then more able to understand the trigonometry of projectile motion.

Figure 1 Rocket launcher project

Students have also been able to represent their understanding of forces and motion through alternative assessments besides tests and quizzes. One of the best ways to see how clearly students understand Newton's Laws was through the use of SAM animation (Figure 2). Students can use cameras and simple computer software to create stop-motion videos to explain physics concepts. Students did some of their best work when they were able to present their ideas this way.



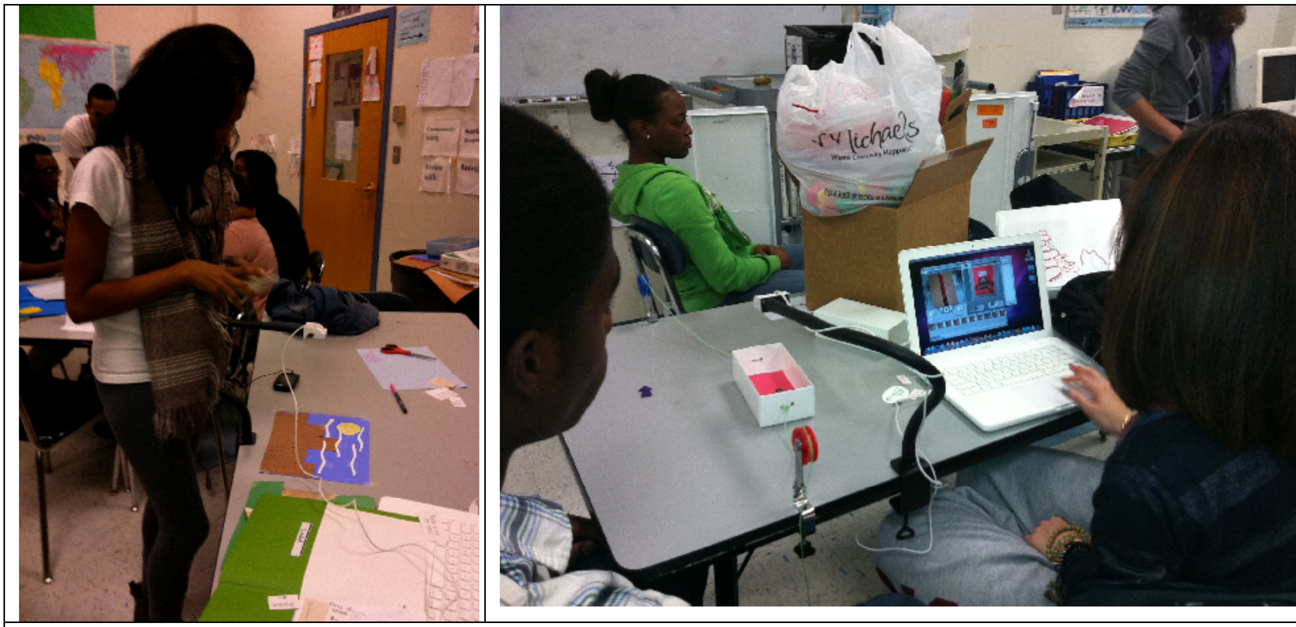


Figure 2 SAM animation studio

Another way students have looked at forces and motion is through the egg drop project (Figure 3). Through this project and the use of the engineering design process, students were able to experiment and refine their ideas while creating their prototypes. It became clear which students understood the ideas behind forces and energy.

Figure 3 Egg drop project

In short, students in the hybrid physics & algebra course have been more engaged in both the science and the math because they have been able to use the engineering design process in numerous hands-on projects to develop and explain their thinking and understanding of physics and math concepts.

Evaluation

Assessing the changes is difficult because we do not have objective data points that can be directly attributed to changes in the STEAM curriculum, that and the fact that the changes have not been fully implemented. We can report that on the state's exit exams for science (MCAS Engineering) we had a 92% passing rate among all 9th grade students taking the test an increase from the prior year of 82%. We also substantially increased the number of students demonstrating advance status on the test (from 2 students in 2010 to 9 students in 2011). These students are now in the 10th grade and will soon be taking the MCAS math exam; it is our expectation that they will show improvement in exam as well. One of the STEAM goals is to increase the number of students making proficiency and reducing those students that passed the test but did not make proficiency. We are tracking the colleges and major chosen by our graduates, but since this is only the second year of our initiative, it will be some time before we can note changes to STEM majors.

Conclusion & Next Steps

Boston Arts Academy is committed to expansion of this process of using EDP in both its math and science classes. It is the conclusion of the STEAM team that using this process better prepares students for further studies in math and science. It anchors the learning in the real world and by giving students opportunities to use this knowledge to solve a problem helps the student retain the information. The EDP provides students opportunities to make and produce works that are original and unique, as opposed to merely repeating formulaic science experiments.

The budgetary and equipment needed to support and maintain the program posses a challenge. Urban inner city students and schools do not have sufficient funds to really invest in large equipment dependant projects. The curriculum is open, meaning that different sets of students develop different types of project and solutions to posed problems; this means that the classroom teacher has to find, order and procure materials with very limited resources. We need to find more economic resources to further expand and support this approach to science and math. Doing and making things takes more resources than paper labs and simulations.

BAA is committed to developing 21st Century Skills in its students and this requires that we change our approach as to how students do and think about science and math. In order for students to fully engage the curriculum, students need to play with and use the information. Having complex projects and exhibition using both the scientific method and the EDP are way for students to internalize the knowledge. The EDP also causes a paradigm shift in the role of the teacher in the classroom; the teacher is not so much as the evaluator, rather the teacher is more of a coach/resource that can be used to help guild the students through the process. This relationship is less adversarial and more collaborative. This paradigm shift makes the student a more active agent in his/her education, student becomes the worker. It also prompts the students to use their minds well. In the end we want students to leave BAA and start their post-high school experiences with confidence, knowing that they can solve problems, work collaboratively with others and use their minds well.

As we continue to seek ways to improve our curricula, it is important that we continue to seek partnerships with institutions of higher learning, such as Northeastern University. It is through these connections that we can improve our staff's skill sets through a number of PD opportunities, and it is also a way for us to get more experts into our classrooms. It is important that we capitalize on any and all opportunities for our students to see what it's really like to pursue a STEM career and to help them realize that they could do that too. Not only are higher educational institutions more able to provide professional development for our faculty, but they are a valuable resource for our students.

We are also very interested in more closely examining the relationship between our math and science courses so that perhaps we can create more interdisciplinary courses that would integrate all five areas of STEAM (science, technology, engineering, arts, and math). We have considered the possibility of an Enginometry (engineering & geometry hybrid) course that would define the 9th grade experience, but we still have much work to do before piloting such a program, including more professional development in the engineering design process for our staff.

Lastly, it is important that we continue to collect and analyze our MCAS data in science and math as we rewrite our curricula and that we continue to monitor where the students are choosing to go to college and in what subjects. The more information we have, the better informed we will be as we change our curriculum.

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