Science STUFF (Science, Society and Technology for Underrepresented Future Fabricators): Curriculum for future makers and designers

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Abstract
This paper documents the year-long process of developing one curriculum module out of several used in formal and informal settings in a rural southern US state. The goal was to develop engineering design-infused STEM activities that used everyday materials, related to students’ lives, had a pro-social focus, met state science standards, and helped youth develop STEM literacy and skills. This process of curriculum design falls into the category of “design experiments” as described by Brown (1992), Collins (1992) and others. Over 375 students were exposed to the Solar Landmine Detectors curriculum over the course of a year and the module was continuously revised based on observations of the students.

Keywords: Middle school; engineering; STEM education

Introduction
Cotton used to be king in the southern US, and with that crop came mills—mills that made everything from string to yarn to fabric to cotton towels and sheets (Hall, Leloudis, Korstad, & Murphy, 2012). The mills kept the economy humming, until much of this manufacturing was automated or moved overseas (Pfannenstein & Tsai, 2004). Then the mills shut down, crumbled, and decayed. In their place came other, more high-tech job opportunities, and now the southern US is in dire need of citizens with better scientific and technological literacy to work in these new factories (Falk & Lyson, 1988).
In many parts of the south, automotive parts manufacturing has moved in, with companies like GE Aviation, Kia, and Briggs and Stratton in our own region. The Southern U.S. is primarily rural, and rural schools need to offer their students more than traditional courses in order to prepare them for the world of work (Herzog & Pittman, 1995). Robotics clubs are becoming more popular thanks to the BEST Robotics and their free curriculum and supplies (Varner, 2016). Many schools still offer a technical career track for students that includes some engineering, but students in college preparatory classes also need education in integrated science, technology, engineering, and mathematics (STEM) (Stohlmann, Moore, & Roehrig, 2012). Although there is a broad trend to develop future makers with technological expertise and skills (Costa, 2017), rural schools have an especially important role in preparing students to fill engineering and technical jobs while also improving scientific and technological literacy (Hutchins & Akos, 2013).

Recent popular press investigations (e.g., Webster, 2014) have indicated that future job growth may be strongest in an area of “middle skill” labor, where the workers have strong technical skills (e.g., computer programming, electrical certifications) but do not have formal engineering or scientific training or even a bachelor’s degree. Labor analyses support these conclusions (e.g., Holzer, 2015) that although many jobs are being automated (construction labor, clerical work, and parts assembly) there is a growing need for skilled labor in fields such as maintenance and repair of machines (including the robots that automate assembly) and healthcare. These new areas of job opportunities require specialized training beyond secondary school.

We, the authors, wanted to develop a curriculum for a STEM class at a rural middle school in a southern US state, and hoped that it would not only teach STEM skills, but also improve STEM literacy, and attitudes towards careers in STEM fields for middle school youth. Design-based STEM curricula have been shown to significantly improve science performance in terms of science concept knowledge, engagement, and retention (e.g., Mehalik, Doppelt, & Schuun, 2008). Our driving research question was:

1) What modifications do we need to make to an existing activity to develop an integrated STEM-focused curriculum that is motivating, engaging, and educative for male and female middle school-aged youth?

Background

The first two authors were approached by the principal of a rural middle school in the deep South, and asked to develop and teach a STEM class. The principal wanted her school to be able to offer more STEM opportunities through a club experience, but the teachers felt unprepared to teach it. This school was located in a former mill town that has experienced a period of economic downturn followed by recent revitalization due to nearby automotive manufacturing facilities.

The goal of this project was to develop curricular modules that tied engineering design concepts to standards-aligned science content to build interest among students in more technical careers. To achieve this, we exposed the students to a range of engineering fields (including civil, mechanical,
electrical, aerospace, and textiles) and engaged them in design challenges each week that incorporated at least one phase of the engineering design process (See Figure 1). Our curriculum design was based on the Tyler Rationale (e.g. Tyler, 1949), which describes curriculum in terms of purpose, objectives, content, approach, and assessment. However, our learner-oriented curricula were developed in collaboration with many others, and therefore the development process is aligned with postmodernist ideas of curriculum development (e.g. Doll, 1993). Based on the literature (e.g. Tyler, 1949; Brophy, Klien, Portsmore, & Rogers, 2008) and our understanding of the development of 6th to 8th grade students, we developed the following design diagram for students to use, which included six phases: identifying a problem, researching the problem, brainstorming solutions, designing a device (with constraints), designing and testing the device, and then presenting the best solution. This design diagram was aligned with the social critical model, which asks students to work in groups in order to solve a problem that is related to the area and the students’ lives (e.g. Toohey, 2000).

Figure 1. Our representation of the Engineering Design Process adapted for 6th-8th grade students.

Curriculum development process

The intent of this project was to develop curricular content with multiple experts in design (Collins, 1992): pre-service science teachers, in-service science teachers, and science education and educational psychology faculty at Auburn University. Our goal was to involve the in-service teachers in STEM curriculum design to build capacity for STEM education at the school; we involved pre-service teachers in both curriculum design and teaching STEM to build their skills as future teachers; all researchers were involved in the process of design experiments as curricula were implemented and changed from iteration to iteration. We embarked on a year-long intervention which involved two university
We operated under the following guiding principles:
1. Curriculum must use everyday materials that are easy to purchase and safe,
2. Curriculum must have a connection to students’ everyday lives,
3. Curriculum must align with a state science standard, and
4. Ideally, engineering solutions should have a pro-social focus.

Research on values and occupational goals has consistently indicated that women are more likely than men to prefer occupations that offer opportunities to work with others and help society (Schwartz & Rubel, 2005; Su, Rounds, & Armstrong, 2009; Lippa, 1998). Men are more likely to prefer occupations that afford status (high income or prestige) and influence. Therefore, we wanted to see our participants develop ideas that fostered collaboration and connect ideas to helping fields.

**Design Experiments or Design Research**

Design experiments, or design research, involves the iterative process of designing, testing, and redesigning a curricular intervention in a real-world setting (Brown, 1992). Formative assessment is key, as it informs the curricular modifications. In the case of this particular work, the authors formatively looked at engagement, attitudes, and dispositions as the intervention was modified from class to class, and semester to semester. Without a positive attitude and interest in the intervention, learning is not likely to take place (see review by Fredricks, Blumenfeld, & Paris, 2004). Once positive attitudes were determined to be established, the curriculum could be modified to capitalize on content achievement.

Design research in authentic settings is fraught with variables that cannot be held constant. In a laboratory setting, curriculum can be tested with many small groups of students with controls and variables tightly controlled. However, in this study we had acoustically-challenged classrooms to deal with, varied classroom management styles, varied teacher interest, varied student backgrounds, and varied student interest and confidence levels. Controlled settings, such a small focus groups, can be valuable for designing that first draft, but refinement requires complex settings (Brown, 1992). We followed several guidelines from Collins (1992) by including teachers as co-investigators, comparing multiple innovations, involving an interdisciplinary team of experts, remaining flexible in our design revisions, and evaluating our success with several lenses.

**Methods**

In this study, we created lessons and activities to develop STEM literacy and skills for middle school-aged youth. At Site #1, called Riverside Middle School (a pseudonym), students met once a week for an hour all year. We worked a total of 92 students over the course of the year. We worked with two groups of 6th grade students, two groups of 7th grade students, and one group of
8th grade students for 16 weeks total (three groups in Fall, two in Spring). At Site #2, called Countryside Middle School (a pseudonym), we met with 250 students in grades 5-8 over the course of two full school days when the school held a STEM fair and students moved quickly through different activities.

While we created, taught, and studied many different lessons over the course of the year, in the following sections, we describe only one of our curricular interventions, and describe the design experiments we performed as we improved and refined the lesson. We chose this lesson to represent our work because it was taught to the greatest number of students, 342, and went through the most iterations. We started out calling it “Solar ArtBots.”

**From Drawing Machine to Solar Landmine Detectors**

**Prototype 1**

We started fall semester 2016 with an old favorite design challenge, sometimes called Scribble Bot or DrawBot, Wobble Painter, ArtBot, or Cup Draw. This design activity can be traced back through several permutations to the 1975 book edited by Bernice Chesler, “Do a ZOOM Do” which was based on activities sent in by viewers of the popular Public Broadcasting System (PBS) children’s’ TV show, “ZOOM.” In the 1975 book (see Figure 2), young Tim Mamis of Brookline, Massachusetts sent in an idea called simply called Drawing Machine. He used markers, a cup, a battery, and a motor to make a cup wiggle and draw on paper (Chesler, 1975). Many others have adopted this approach and use the same materials - a plastic cup, battery, and motor with markers to make the device wiggle on the paper and randomly draw. Nothing steers the device. Because there is an unbalanced weight on the motor shaft, it just randomly wiggles. However, if carefully designed, it can wiggle in a particular repetitive pattern and create really interesting designs.

![Figure 2. Original drawing machine concept from Bernice Chesler's “Do a ZOOM Do.”](image)

**Prototype 2**

When we introduced the activity to one group of 6th and one group of 7th grade students at Riverside Middle School, we decided to use solar cells instead...
of batteries to electrify the device. We also provided art decorations and yards of duct tape to secure markers and motors. Sixth grade students were especially creative in decorating their bots. We brought a shop light with an extension cord in case the sky was too overcast for the sun to make the solar cells work. The choice of solar cells was one of convenience—we had them readily available, but not batteries. However, the decision was fortuitous since it taught youth about an alternative energy source, and the design provided a natural circuit switch—shade! When the solar panel was in the shade, the bot stopped wiggling. Students worked in teams to negotiate how they would solve problems together.

We taught students about circuits, STEM, robots, experiments, predictions, and prototypes. For many of the 6th graders, this was their first experience creating circuits or doing any sort of engineering. We had to assure them they would not get shocked! There were 25 students in one 6th grade class (3 of them female), 25 students in the other 6th grade class, and 30 students in the 7th grade class (almost half female).

The students worked indoors to build their bots, and then took them outside to test them (luckily on a sunny day). While they found the activity to be fun and novel, they encountered problems with the cups falling over, the tape coming unstuck, limited space to place both the solar panel and the motor, and limited design options. Placing paper on the sidewalk proved to be a better idea than placing it on the grass. See Figure 3. These frustrations appeared to be demotivating based on reactions from the youth, so we set about to remedy the problems. This resulted in the changes made for prototype 3 which mainly concerned the chassis and room for placing the motor and solar panel.

All student groups were successful in getting their ArtBot to draw in one 50-minute class period, which was a great way to start off the school semester.
Prototype 3

The next iteration of ArtBots was over the course of two days at a STEM Day at Countryside Middle School in October 2016. All students in grades 5-8 visited our outside station in a parking lot, and we taught 10 classes over the course of two days for a total of 250 youth. Prior to this two-day extravaganza, we revised the curriculum and the materials in the following ways:

1. We re-wrote the curriculum to include the Engage and the Explore phase of the 5E Learning Cycle (Bybee et al., 2006). For the Engage phase, we passed around a solar grasshopper that wiggled on a plastic tray in the sunlight. See Figure 4. We asked youth to observe the grasshopper and guess what was making it jump around. We pointed out the small, lopsided motor mount. Then we asked, “What would happen if we dipped the grasshopper feet in paint?” We then passed out a box of materials to each group of 3 students. As the Explore phase continued, students were to demonstrate that they could successfully complete a circuit between their solar panel and motor in order to get their motor to run. After some brief instruction on circuits, switches, and motors, students were tasked with determining for themselves, through trial and error, where best to position the solar panels, motor, and markers to create a functional ArtBot. Instructors posed questions as needed to help students troubleshoot their designs, but tried not to give answers.

Figure 4. Solar grasshopper

2. We replaced the plastic Solo cups with white baskets as the base, and purchased short markers all the same length. Students still required tape to secure the markers, solar cell, and motor, but they had much more flexibility for placing components, and the bots were more stable, which was helpful since it was a quite windy both days. We were surprised when one group decided to tape their markers inside the container. We dubbed their bot “In Cog Neato” and decided to include the idea in the next curriculum prototype. See Figure 5 for an image of two bots, including “In Cog Neato.”
Most groups were successful, even given the short time frame, but we ran out of tape and found it to be rather frustrating at that. Additionally, the amount of tape students were using often weighed down the ArtBot so it could not move. This demotivating factor spurred us to begin considering an alternative to tape. Noticing that the white plastic containers had natural “rails,” the first author had the idea to use Velcro straps for the markers, and Lego pieces on the top of the white container for snapping on the motor and solar panels instead of taping them.

**Prototype 4**

This phase of the curriculum design entailed the birth of our little bot named “Francine the Dancing Machine.” See Figure 6. She had Velcro straps around the basket rails, and a “Lego” top printed with a 3D printer, but this process proved to be too time consuming and resulted in some overnight accidents with melted plastic, so subsequent white plastic containers got flat Legos hot-glued to their tops. Because mass production of 3D printed “Lego” tops was too challenging and did not occur in this prototype of the curriculum, it was not tested by students.
Prototype 5

We were able to introduce ArtBots to a new class of 6th grade students during November 2016. The improvements visibly reduced frustration and gave youth more design options. They could move and position the markers easily with the velcro straps, and could place the solar panels and motors in a variety of places on the top with Legos (See Figure 7). Most importantly, the streamlined process of placing the solar panels and motors allowed most groups to test out two different versions of their bot during one class period. We met with this class two weeks in a row, and added a design challenge during the second week. We tasked groups to improve their ArtBot so that it made better art. We asked youth to draw their designs and document the design changes. See Figure 8. Introducing iterations was key to making the curriculum more truly aligned with the engineering design process.
Figure 7. Lego pieces glued on top in various configurations

Figure 8. Drawings created by solar ArtBots in two trials of the design

One of our authors reflected in her journal,

“Students are challenged here to develop not only multiple prototypes, but to critically examine the structural differences between their prototypes and can even analyze any differences they observe in robot behavior as evidenced by the designs produced… the art becomes evidence… data!”

Prototype 6
Spring 2017

The following semester, we modified the curriculum further for a group of 12 8th grade students (10 male and 2 female). In February, we taught ArtBots in the same way we did for Prototype 5, and since it was just before Valentine’s Day, we challenged the students to make cards for their teachers. This was not a popular idea in the 8th grade class and we observed much less engagement than previously. So, the following week, we decided to set the design challenge into a context that had societal relevance instead of “holiday” relevance. We got
together and brainstormed, and came up with an idea (see Figure 9 for evidence of structured brainstorming!) that had to do with landmines.

Figure 9. Brainstorming in the classroom

Landmines present a terrible problem for people around the world since there are so many live mines left from wars. It’s estimated that 100 million unexploded landmines are distributed in more than 64 countries. The greatest problems are in Africa and the Middle East. Landmines maim or kill 500 people each week. Most are innocent civilians, and most horrifically, children who pick them up thinking they are toys. There is a landmine-related death every 20 minutes. See Figure 10 for landmine danger signs around the world. We taught the students about these landmines, and showed them pictures of children missing limbs, a map of where the landmines are located, and pictures of how much like toys they look. We asked students to brainstorm ways people should locate and destroy these devices. We showed students some ways that destroy landmines. Especially engaging was a video of a Mine Kafon, which sweeps a field by blowing in the wind (Focus Forward Films, 2012). That led them to connect this new information with the ArtBots they had built the previous week.
We tasked the students with the inquiry activity challenge of using their Solar Artbots to detect landmines. The “landmines” were white stickers on a field of blue paper (Figure 11). Given a certain amount of time, their “bot” had to color on as many white stickers as possible. We set the goal at 5 landmines per minute, and challenged each group to meet the challenge. A “drone” (their arm) dropped the “Landmine Detector” anywhere on the large blue field full of white dots, and they turned on the shop light and watched the landmine detector work. They collected their data, refined their device to sweep a wider area, and tried again with a revised device to collect more data. There were additional constraints in this phase of the curriculum design, particularly that materials and time to design and build were limited, but the entire lesson was fast paced given the need to detect as many landmines as possible on a blue paper minefield in a minute.
The addition of a real life scenario for what was otherwise just fun artsy design was motivating for the youth. They drew their landmine detectors in their engineering notebooks and tried to capture top, front, and side views. Each group had a separate marker color so we could track the number of “landmines” detected. When asked whether the students preferred the activity without landmines to the activity WITH landmines, they unanimously voted for the latter idea, stating that it had a real-life context that was interesting and challenging. Our landmine lesson shed light on a real-world problem with a simulated solution.

Summary

Table 1 illustrates how we applied engineering design principles to designing engineering design lessons. It depicts how “Solar Artbots” became “Solar Landmine Detectors.”

Table 1. Summary of curriculum design changes

<table>
<thead>
<tr>
<th>Prototype</th>
<th>Prototype 2</th>
<th>Prototype 3</th>
<th>Prototype 5</th>
<th>Prototype 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student Population</td>
<td>6th and 7th grade students</td>
<td>5th - 8th grade students</td>
<td>6th and 7th grade students</td>
<td>8th grade students</td>
</tr>
</tbody>
</table>
Changes Started with solar artbots with solo cups, duct tape construction, assorted markers, and decorative options (feathers, pipe cleaners). Objective was to make art.

Construction used plastic organizer bins to give more options on motor placement; bought consistently sized markers.

Use shop lights instead of outdoors, students able to make two prototypes and compare in one 50-minute class period. Used double sided Velcro strips to replace most of the tape needed. Glued Lego pieces to top for easy placement of solar panels and motors.

Expanded context to detecting landmines; and added a competition/challenge element and a meaningful context.

Students reported preferring landmines application; wanted to learn more about them.

Table 2. These changes were compared to their change in landmine detection performance (i.e., number of dots touched by robot). Students reflected informally (verbally and in engineering notebooks) on how changes in their design led to changes in performance. Many students had additional ideas for further improving their robot if time had allowed.

Table 2. 8th grade group modifications to Solar Landmine Detectors

<table>
<thead>
<tr>
<th>Group</th>
<th>1st Round</th>
<th>2nd Round</th>
<th>Reported changes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of landmines detected</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>7</td>
<td>8</td>
<td>Moved markers from inside to outside the frame</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>NA</td>
<td>Was not able to revise in time; reported trying to move markers to outside. Talked about lopsided bot, wanting it to be a “low rider”</td>
</tr>
<tr>
<td>3 (All girl team)</td>
<td>9</td>
<td>8</td>
<td>Swapped a melted-looking solar panel with another team; new panel seemed lighter; they got less movement on second try</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>7</td>
<td>Move motor to new location and secured with more tape</td>
</tr>
</tbody>
</table>
Placed motor differently (off balance?) to get faster spin and more movement

**Results**

Our goal was to develop curricula that

1. used everyday materials that were easy to purchase and safe,
2. was engaging,
3. had a connection to students’ everyday lives,
4. aligned with a state science standard, and
5. had a pro-social focus.

For the Solar Landmine Detector curriculum and others we developed, we met our goals. We observed that students in the 8th grade classroom using Prototype 6 of the curriculum were more engaged in the revised activity. Our definition of engagement included noisy, problem-focused discussions (e.g., offering competing solutions and deciding which approach would be best), and excitement about robot performance (e.g., cheering, encouraging the robot, guffawing, etc.). When asked to compare this activity with the art-focused lesson, students reported unanimously that they preferred the landmines version, because it had a purpose and a real-world application.

Our research question was, 1) What modifications do we need to make to an existing activity to develop an integrated STEM-focused curriculum that is motivating, engaging, and educative for male and female middle school-aged youth?

Data gathered from informal observations and discussions with youth and reflections among the authors indicate that we indeed developed engaging and educative curricula for all students. The lack of hard data (surveys, formal interviews, etc.) from youth is a limitation, as we were interested in developing the curriculum with a wide variety of youth in varied contexts, and did not have time to collect solid data given our time constraints. Our next step is to create valid and reliable pre- and post-tests, and formally assess student learning with the curriculum we designed.

**Implications and Next Steps**

Basic research is critically needed to understand how STEM literacy and skills are related to a variety of content areas and how they can help or hinder students’ performance in STEM courses and fields. The goal of our basic research program was to understand how to design engaging STEM curricula that had the potential to teach them core science and engineering practices. We learned that many iterations are necessary with a wide variety of youth in many contexts both formal and informal. Our focus was both on the rigorous development and testing of our curricula, as well as researching its efficacy in inspiring youth to tinker with materials and design and construct complex devices from simple materials.
References

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