Enriching an Informal Engineering Education Program with Social Relevance and History for Middle School Girls

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***Abstract*—Two educators collaborated to design and test a one-week summer course for middle school girls on sound, engineering, and invention as an exemplar integrated STEM program that draws upon rich historical and social contexts with the goal of attracting and retaining students in STEM. An engineering design project and an invention project formed the core of the course. Music and related technologies served as the unifying theme intended to tap into the interests of youth. Historical primary sources and writing about invention and innovation provided additional entry points into engineering as a human and creative endeavor. Exposure to female inventors, scientists and engineers was also planned as a way for the girls to become acquainted with positive role models. Included in this paper is a discussion of the underlying philosophies that influenced the design of the learning experiences for youth underrepresented in STEM.**

Keywords— engineering, integrated STEM, informal, primary source, history, sound, middle school, girls

I. Introduction

In 2013, women made up roughly only 15% of the engineering workforce [1]. Attention has been paid over the preceding decades to broadening access to and participation in engineering for girls and underrepresented minorities in engineering [2]. Based on this previous work, our team developed a one-week summer course for middle school girls that focuses on engineering and invention. The course provides a model for other integrated STEM programming that draws upon rich historical and social contexts to attract and retain young people in STEM. The course is grounded in an engineering design cycle focused on music, sound, and related technologies in an effort to tap into the interests and life experiences of the girls in the course. A discussion of the underlying philosophies behind planning the learning experiences is presented here.

II. Influences on Program Design

Although a framework for teaching engineering in the K-12 setting has yet to be firmly established, a two-year study by the National Academy of Engineering recommended that K-12 engineering learning focus on design and developing engineering habits of mind, including systems thinking, creativity, optimism, collaboration, communication, and attention to ethical considerations [3]. Planning around a hands-on design project and an exploration into invention and innovation were the initial intentions for a summer enrichment program based on reports of positive outcomes for middle school youth involved in these types of activities [4], [5], [6]. In developing the curriculum for a girls-only section, special attention needed to be paid to engaging the youth in a way that could make engineering approachable and help to establish their identities as STEM-capable students. The promise of attracting girls to STEM fields and establishing a continued interest through participation in a well planned out-of-school event was reported by Ceci, Williams and Barnett [7]. This opened the door to designing lessons that integrated engineering with other disciplines in a way that mattered to these middle school girls while still focusing on design through group activities that fostered systems thinking, creativity, optimism, collaboration and communication.

The first step was finding a theme for the week that was relevant to the students. In designing an integrated STEM curriculum, Berland suggests that the first best practice is to "contextualize all student work within STEM-design challenges" [8]. A theme that increases student interest levels has been shown to better develop their sense of self-efficacy and perseverance when encountering difficulties in their learning [9], [10]. Furthermore, "links to students' culture and community are important" in promoting a sense of identity as a capable STEM learner when participating in integrated STEM programs [11]. Music, sound, and related technologies was chosen as the theme for the week. Music and related technologies are ubiquitous aspects of culture and of the lives of youth and should serve to put the engineering investigation into a meaningful social context.

Interest in problem solving in girls can indicate an interest in all four STEM subjects, but to indicate that they might be specifically interested in engineering, girls need to also show interest in creativity and design [12]. Adding an investigation of the concepts of invention and innovation was intended to stimulate creative tendencies. A review of hundreds of studies related to why women are underrepresented in STEM fields also found that "girls who have high math abilities are more likely than boys who have high math abilities to also have high verbal abilities" [7]. This pointed to the idea of integrating writing into the week's plans in a more robust way than might otherwise be planned in a STEM program. Writing about inventions is a natural melding of these concepts.

Finally, historical primary sources related to sound recording and playback were added to the program to provide another pathway for accessing the engineering and science portions of the course. In researching the use of historical case studies to teach concepts related to the nature of science, Allchin, Andersen, and Nielsen reported that the "curricula that document the most significant gains seem to involve activities that engage students in authentic (even if simplified) problem solving—that is, adapting general inquiry strategies to a concrete case in historical context" [13]. The nature of science concepts that relate directly to the nature of engineering that were shown to effectively be taught using historical documents included problem-posing, problem-solving, analysis of process and product, and an understanding of the necessity of error and revision in the cycle of improvement [13]. In general, the use of primary source documents in learning environments has shown to "allow [students] to develop their critical and analytical thinking skills," especially when used as a collection related to a specific theme [14]. Fink also cites the use of original sources as the most desirable method to promote active learning when gathering information and ideas [15]. However, when successfully integrating primary source documents into lesson plans, time must be made to "closely observe the documents' features, bring prior knowledge to bear, speculate about causes and consequences, make personal connections, and use evidence to support their speculations" [16].

III. Outline of Program

The summer enrichment course will meet five hours each day for five consecutive days. Active learning, team projects, and chunking will be key to keeping these young students engaged over such long stretches of time. A brief overview of the plan is given here with more details in the subsequent paragraphs. A roadmap of the course that will be used to orient the girls throughout the week is shown in Fig. 1 and will be referenced in the overview below. The roadmap is written using questions that the students will investigate and activities they will engage in rather than topics the teacher will cover so as to set up an expectation of active engagement and personal connection from the beginning.

Starting with the question "What do these old machines do?" students will be introduced to the early stages of sound recording and playback technology using historical photographs and documents. This will naturally lead to the question "What is sound anyway?" that will be explored using a physical model of a gramophone and modern speakers. Linking this new physical understanding of sound to the mechanisms that generate it takes place during the "How do they work?" step on the roadmap. Then, by undertaking an authentic engineering design-build-test cycle of their own gramophone, learners will engage in nearly all of the middle school Next Generation Science Standards (NGSS) engineering practices. Primary source documents will again be used to link structure to function by comparing a phonograph to a gramophone while answering "What would be a different way to do this?" The ideas that attempts to improve an existing product or method often lead to an invention and that the

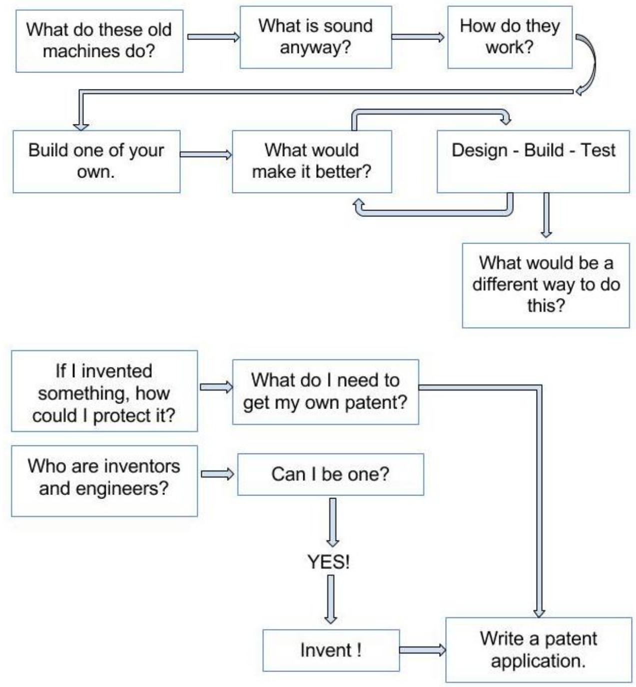

Fig. 1. Roadmap of the course

phonograph and gramophone where individually patentable objects will act as a transition to an introduction to intellectual property protection as we ask "If I invented something, how could I protect it?" The students will learn the basic components of a patent by engaging with some simple patents first and then with more complicated ones. To allow them to comfortably answer "What do I need to get my own patent?" they will also practice writing technical descriptions and making drawings. "Who are inventors and engineers?" will be answered by both researching inventors and practicing the creative skills necessary to invent. Reference materials that stress the diversity of female inventors and engineers will be provided so as to increase the possibility of the students answering the question "Can I be one?" with a YES! Finally, the week will wrap up with the students being challenged to come up with several potentially patentable ideas and then to write a provisional patent application for one of them. The following paragraphs provide more details about each aspect of the program.

Upon applying to attend this academically selective camp, candidates are asked to complete a Readiness Challenge. The intention of the exercise is to give them an idea of the type of subject matter and investigations they can expect at the particular camp session they choose. Careful completion of the activity also shows a commitment on the part of the applicant, which can be highlighted in their teacher's recommendation letter. For this session, applicants are asked what they know about the work of engineers and what everyday problems they think engineers could fix. They are asked to explain what they find interesting on the "How Stuff Works" website and what they would like to build if they had the supplies to do so. They are also asked who their favorite inventor is, what they would like to invent and what they find to be advantages and disadvantages of working in a team. Some of their answers will be used as starting points for camp activities involving invention and might also be useful when assessing progress toward learning goals after camp is over.

The session will be started by activating prior knowledge surrounding sound and its recording and playback through the analysis of historical primary sources related to the invention and development of the phonograph and gramophone. Library of Congress (LOC) materials including photographs, newspaper articles, patents, and engineering drawings will be used, most of which are from their collection on the 1894-1895 work of Emile Berliner [17]. The approach taken to this guided analysis is outlined in the *LOC's Teacher's Guide: Analyzing Photographs and Prints* [18]. Allowing the students to identify and note details, make hypotheses, and then generate questions about the printed material engages their natural curiosities. In addition to acting as an introduction to the week's work, this activity provides opportunities for students to consider how function is determined by structure as well as begin to think about systems, both of which are NGSS cross-cutting concepts.

A hand-cranked gramophone made with household items will be presented next. The students will be asked to operate the gramophone based on their understanding of its operation gleaned from the previous activity. The students will also be encouraged to inquire into the nature of sound waves through physical contact with the vibrations being generated by a modern stereo speaker operating with its diaphragms exposed and by tuning forks dipped in water. The concept of energy conversion and the NGSS Disciplinary Core Idea PS4.A, that a sound wave needs a medium through which to be transmitted, are both easily discussed at this point. Students will be asked to make a visual representation, in the form of a map or flow chart, of the energy conversion taking place in the gramophone. Extension into mapping the energy conversion into sound occurring by different means in the speaker and the tuning forks is possible depending on their level of understanding at that point.

We will mention that the demonstration gramophone does not work very well and challenge the students to offer innovative design improvements. The structured, iterative manner of solving problems used by engineers will be offered as a reasonable approach to take because iterating through several cycles of investigations is more likely to lead to an optimized solution. The engineering design cycle will be defined for them and posted prominently around the room.

In groups of three to four students, they will first build a gramophone similar to the demonstration unit, which is made from a cardboard box, a plastic food container, a pencil, a pipe cleaner, tape, white paper, and a needle. Before working in a group, a discussion will take place surrounding the advantages and disadvantages of group work that they identified in their Readiness Challenge. The students will be guided in developing their own set of rules for respectful teamwork and they will be prominently posted.

After building and operating their gramophones, each group will be coached in writing up objectives for improvements and constraints. The constraints will be driven primarily by the materials provided for them with which to make their improvements. Brainstorming for alternative means to meet the objectives will take place after instruction in the rules of successful brainstorming. Teams will then be asked to write up a test plan that includes how they will evaluate the effectiveness of their alternative solutions. Recognizing that changes must be tested independently is an important step at this point. Finally, all teams will make their tests, evaluate their results and combine solutions to optimize their designs. Sharing of ideas and results amongst groups can lead to a discussion about the cooperative nature of engineering projects and further refinement of their products. All parts of the NGSS Disciplinary Core Idea MS-ETS1 will be practiced during this exercise.

To reinforce the idea that there are multiple means to meet a set of functional requirements, primary source documents will again be used to link structure to function in a gramophone and in a phonograph. Copies of Emile Berliner's sketch of a gramophone [19], a sketch of Thomas Edison's phonograph that appeared in Scientific American [20] and the 1878 patent drawing of Edison's phonograph [21] will be provided to the girls. Given that the different structures of these objects ultimately have the same function, the students will be asked to identify the functions of the parts of both machines by labeling the sketches and then producing an energy flow chart for the phonograph.

Having designed, built and tested their own innovations, the group will now transition to discussing the idea that innovative ideas are valuable and inventors need legal protection for their creations. They will be told that the phonograph and gramophone were considered to be different machines and were therefore both given patents. Their prior knowledge of intellectual property rights will be assessed which will lead into an introduction to intellectual property protection in the form of patents, copyrights, and trademarks. Their understanding will be checked using a scavenger hunt for patents, trademarks and copyrighted text on common items.

A deeper discussion will take place surrounding patents in particular. The concept of applying for a patent will be introduced and the basic parts of a patent will be explored: drawings, technical description and claims. Although the students will have interacted with engineering drawings of a gramophone and phonograph previously, patents for simpler items will be used now. They will learn that an average person should be able to build a patented item from its drawings and description by doing so with a 1882 patent for a flip book "optical toy" [22] and Juliette Low's patent for a paper container that can hold liquid [23]. They will also practice descriptive writing and drawing using an exercise designed to improve their sense of observation, creative thought and expressive writing.

Moving into the last part of the class - "inventing" something and writing a patent application for it - the students will be asked to reflect on what more they think they need to know or practice to be able to invent something. An emphasis on personalizing the experience and encouraging them to plan for their own success adds dimension to the experience and improves the possibility that it will become a significant learning experience for them [24]. To inspire them and boost their confidence, they will be asked to research inventions and write short paragraphs about several of their choosing. This activity was planned in part because of the recommendation of Mosatche, et al., that exposing participants to role models is an important part of an informal STEM program for girls [5]. After sharing and editing, they will add their invention descriptions to the Lemelson Center's "Places of Invention" online map [25]. Exploring the difference between invention and innovation may also serve to inspire the students as they find that innovations are often easier to develop than an invention, even though both are patentable. Participants will sort cards with examples of inventions and innovations into categories that make sense to them, before the distinction is drawn between the two terms as defined in patent law.

Finally, working in teams again, attendees will develop original ideas of how to build something new or improve on an existing product or process. Answers given on their Readiness Challenge can act as a starting point, but they will be encouraged to think even more broadly now. Formal decision-making techniques will be introduced for them to use in choosing a single idea that they consider their best. Their final product will be a preliminary patent application, including a technical description, drawings, and claims that they will develop as a group and share with the class and their parents.

IV. Further Work

As a work in progress, the mechanisms by which the effectiveness of this program will be assessed have not yet been developed. Because of the nature of the program, there will not be a control group of students who go through a program without the enhancements described here against which to compare outcomes. Before and after assessments and self-reporting of attitudes and perceptions can be used to measure overall progress against goals, but the competitive selection process used to choose participants will need to be taken into consideration when designing these assessments as participants will tend to be interested in and possibly knowledgeable about engineering before they arrive. Methods of assessment consistent with those described by Fink [15] will be integrated as appropriate.

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