The Electric Notebook: An Open Source Innovation to Develop an Engineering Mind in Children through Making Simple Circuits, Simple Programming, and Simple Robots

Jeannine A. Huffman
Teachers College of San Joaquin
2857 Transworld Drive
Stockton, CA 95206
+1-209-241-6657
jhuffman@sjcoe.net

ABSTRACT

In this paper, how children learn by doing is discussed as it relates to equity barriers to making and tinkering as a means in developing an engineering mind in children. The electric notebook is an equitable solution for teachers or schools to prepare children for future high technology STEM careers. Through the process of making a series of low-cost simple circuits and programming lessons inside a notebook, children complexify each project, and eventually are challenged to build a simple robot. The purpose of making the electric notebook is to engage children's natural curiosity in learning Next Generation Science Standards (NGSS) engineering requirements through personally meaningful and playful creations as an alternative to the current pedagogy of curricular memorization to meet standardized testing. Arguably, democratizing engineering is possible when children make things from scratch without expensive proprietary robotic kits. Kits often over-simplify the very technology children need to deepen their understanding of how things work. The untoolkit idea of buying inexpensive components separately is a key to removing equity issues which focus primarily on children and seldom address teacher and school access to technology.

Categories and Subject Descriptors

K.3.1 [**Computers and Education**]: Computer Uses in Education.

General Terms

Design, Human Factors

Keywords

engineering, electric notebook, learning by doing, making and tinkering, equity barriers, simple paper circuits, simple robot, programming, Arduino, ATtiny85, untoolkit, constructionism, engineering mind, circuit stickers, copper tape.

1. INTRODUCTION

Children of all ages and color love to innovate, make, and tinker with their hands and what better way to develop an engineering mind, or "maker mindset" [7] than by allowing them to learn by following their natural curiosity? The electric notebook is a simple plain notebook where a child fills each page with personal drawings, poems, or other artwork, and adds a thin electric circuit on the underlying page to illuminate their creation with LED lights or circuit stickers. On each new page, the child makes a slightly more complex circuit and the notebook becomes an artful collection of lessons in circuitry. By the time the notebook is filled, a child will know complex circuits, and the programming needed to design and build a simple robot (see Figure 1).

Figure 1. Simple Green Dragon Robot programmed to appear to breathe flames that move back and forth. Made from scratch using an Arduino, LED light, servo, and foam core.

The electric notebook idea was inspired by Jie Qi, Natalie Freed, and Nexmap's paper circuit 21st Century Notebooks and is a novel approach to meet STEM and NGSS engineering standards of integrating technology and engineering design and modeling concepts of fabrication and prototyping [7]. The purpose of the electric notebook is to equitably engage all children in engineering through making inexpensive projects by hand to learn circuitry, programming, and robotics and serve as a guide for educators in meeting NGSS [1], [13], [16], [26].

2. LEARNING BY DOING

Stager [25] called this "learning by doing" process Papertian Constructionism and was based on the concept of constructionism introduced by Seymour Papert [20], [21]. Papert equated engineering with making and tinkering, which greatly popularized the ideas of making and tinkering. Papert simplified for us how children learn technology best, "If you can use technology to make things you can make a lot more interesting things. And you can learn a lot more by making them" [25]. Papert's research [20], [21], [25] involved teaching children to program with computers and was based on his theory that "knowledge is socially constructed and best achieved through the act of making something shareable."

2.1Democratizing of Invention

Blikstein's [2], [3], concern for "democratizing of invention" led him to design the FabLab "where students could safely make, build, and share their creations." Blikstein's research results showed children from low-income schools designed and created more sophisticated projects that were empowering, and helped raise their self-esteem [2]. Vossoughi, Escudé, Kong, and Hooper [27] added that providing access did not solve equity issues but rather "lies in the how of teaching and learning: specific ways of designing the learning environment." Access to engineering does not address the low representation of girls and children of color entering STEM careers [9], [11]. Reasons for low numbers of African Americans and Latino/as entering computer science or STEM fields according to Margolis [11] is the lack of computer and technology "access to resources and appropriate classes."

Carnevale, Smith, and Strohl [4] stressed there is a demand for science, technology, engineering, and math (STEM) positions as "STEM fields drive our innovation economy." Within STEM are computer science, robotics, programming, and design thinking, which traditionally have not attracted many children. The National Education Association [15] supported Vossoughi et al., [27] and Blikstein's [2] findings that schools pressured by standardized testing "narrow the curriculum to focus on tested subjects, leaving little time for other subjects and learning activities." Martinez and Stager's [13] idea of bringing making and tinkering to the classroom inspired teachers to introduce engineering concepts through playful and fun activities as an alternative to the increasingly common pedagogy of test-focused rote memorization [2], [10], [12], [26], [27].

The Maker Movement goal of making "every child a maker" [7] gained the attention of teacher-leaders, schools, and districts as it aligned with the 3-dimensions of NGSS. Engineering modeling, technology concepts, and science cross cutting practices include critical thinking, problem solving, the design process, circuits, computers, software programming, and robotics [1], [2], [12], [17], [19]. The National Science Foundation [16] was interested in "How can making be used most effectively to help students of all backgrounds learn." Teachers, schools, and districts lack resources and technical knowledge of how to introduce making and tinkering engineering concepts and projects into the classroom to meet NGSS goals and how best to attract, engage, develop, and sustain children's interest in STEM [2], [10], [11], [12], [14], [17], [26], [27].

2.2 The Innovation

One innovative way to develop the engineering mind in children is to introduce them to the electric notebook where they make simple paper circuits that light up inside their notebook through a series of lessons. Engineering is often seen as too difficult to learn, however, making a simple electric notebook hooks children in a stimulating and creative way that may engage and keep their attention [2], [27]. Children do not even know they are engineering or prototyping when making paper circuits and this helps bridge the steep learning curve [22].

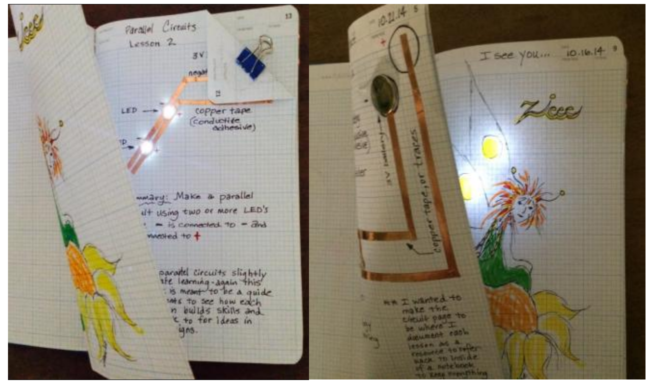

Figure 2. Electric Notebook made with simple and parallel copper tape circuits, circuit stickers, and 3-volt coin battery.

The first step in growing a little inventor involves [24] creating a colorful drawing in a notebook. On the underlying page, children design their first simple circuit by taping down peel-and-stick copper conductive tape, a Chibitronics [5] LED Circuit Sticker light, and a 3-volt coin cell battery (see Figure 2). Total cost is less than two dollars for the first project. When their drawing lights up, children are immediately engaged and delighted because they have instant feedback. Children are quickly able to create a simple paper circuit in a single class period. Simple circuits lead to parallel circuits, and soon children are drawn into using an AVR Tiny programmer from Sparkfun to program an inexpensive ATtiny85 microchip to illuminate their notebook. Each circuitry lesson is drawn, designed, and created inside the notebook providing documentation and programming steps that children will refer to later when creating their first robot.

From there, children design and build a simple moving robot without buying expensive proprietary, sometimes consumable kits that are difficult for teachers, schools, and districts to afford. Starter engineering and robotic kits begin upwards of $200 per student and are a major hindrance in adopting engineering curriculum, thus limiting access for most children and raises equity issues [2], [3], [14], [27]. Mellis, et al., [14] were concerned that kits, though easy to use, constrain creativity and suggested an "untoolkit" that would not "obscure the technology they seek to make accessible." The Red Cardinal Robot was designed by a 12th grader without a kit and made from scratch (See Figure 3).

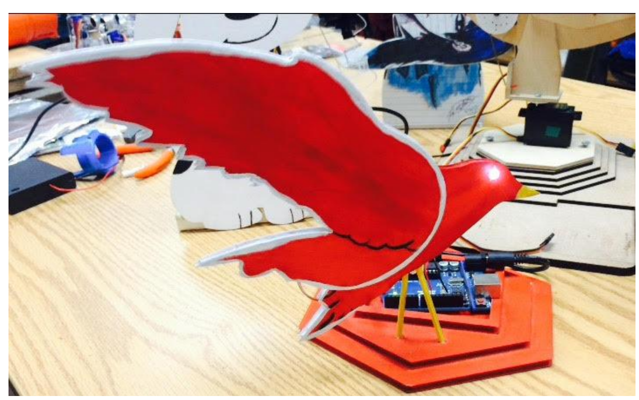

Figure 3. Red Cardinal Bird Robot fabricated on a CNC laser cutter and programmed with Arduino to control a servo.

Tinkering and making involve exploring, questioning, designing, wondering, revising, and redesigning, and it is through this iterative thinking process, or critical problem solving that the engineering mind is developed by experiential learning. Children feel empowered when making things from scratch, and this truly is the engineering experience children need to have to spark innovative thinking and motivate them to further explore and invent [1], [3], [20], [21].

2.3 Programming is Fun

Often the question is asked, if it looks like fun are they learning? Petrich et al., [22] "contend that tinkering activities designed to support engagement, intentionality, innovation, and solidarity provide singularly accessible opportunities for learners to engage in scientific and engineering practices that are both epistemologically and ontologically meaningful." This allowing of children to deepen their knowledge and self-confidence through fun and playful projects fosters complexity and their engineering mind naturally develops [25**]**. At this point it is important that children see that making the electric notebook is not difficult. Once children are comfortable with soldering copper traces, they can be eased into programming 11 lines of code using the Arduino.cc platform. Knowing circuitry is the foundation for simple programming, and without this knowledge of programming, a child cannot make a simple robot.

Figure 4. Complex robot puppy fabricated on a CNC laser cutter programmed to blink eyes and tail to wag.

Drawing on the research of the untoolkit, [14] children will need to learn how to write programs from scratch to understand how code works in order to think critically in how to design the actions and movements of their next projects. The danger in becoming dependent upon Arduino.cc pre-programmed libraries or sketches is that children will not be able to troubleshoot their robots in future projects. The robotic puppy was made by a 6^{th} grader who designed her first puppy on 2D software to wag a tail. Her second puppy was made on a CNC laser cutter and she programmed the dog's eyes to light up and blink and tail to wag (see Figure 4).

3. BEYOND THE SIMPLE ROBOT

Future innovations integrating the electric notebook with a science application might gain inspiration from Natalie Freed [8] who added intricate wiring and beautiful water color paintings of the San Francisco Bay in her notebook *The Tide Book.* Freed programmed blue LED lights to light up as the tide level rose and fell in the San Francisco Bay. Freed used wifi to capture real time data retrieved from the National Oceanic and Atmospheric Administration (NOAA) to combine science, technology, engineering, art, and math into a truly integrated STEM project (see Figure 5).

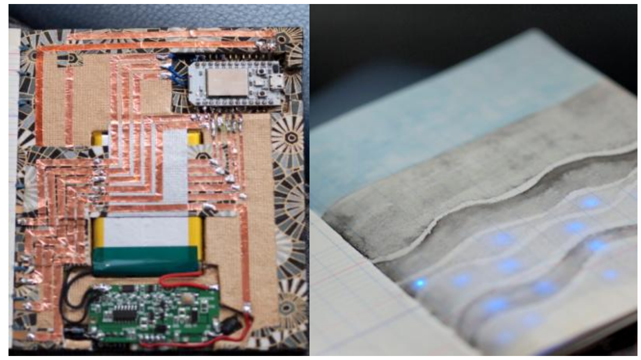

Figure 5. The Tide Book captures real time data with wifi. Images from Natalie Freed and Jennifer Dick for NEXMAP.

Creating the electric notebook can lead to interactive physical computing, or programming a microchip to control a physical object. In this engineering example Jie Qi created *The Dandelion Painting* [23], with complicated paper circuitry, microchips, sensors, and sound. Qi programmed her painting so that when she blew on a dandelion with a sound sensor underneath, the flower LED seeds flew away and triggered other dandelion flowers to disperse their LED seeds (see Figure 6). Qi powered her notebook with a lithium ion battery with LED lights timed to music. Qi showed that engineering and technology can be connected to art and creativity and meet NGSS at the same time.

Figure 6. The Dandelion Painting showing complex circuitry. Photos used by Permission from Jie Qi.

Blikstein and Krannich [3] declared that making is "a major chapter in this process of bringing powerful ideas and expressive media to schoolchildren." The innovative teacher understands these powerful ideas and systems thinking [10], [13]. The electric notebook can be piloted by a single educator innovator with relatively inexpensive resources. Nexmap [18] offers open source paper circuit and programming project downloads with instructions, videos, and resources. Chibitronics [5] has excellent open source tutorials and LED Circuit Stickers. Dick, Qi, Cole, and Sansing [6] provide open source curriculum.

4. CONCLUSION

Developing an engineering mind in children using the electric notebook and paper circuitry can begin as early as elementary school. An innovative teacher or forward thinking leader will recognize the possibilities of integrating STEM and NGSS engineering standards of circuitry, programming, and robotics through such a simple and inexpensive introductory project as the electric notebook [13]. The electric notebook allows children to experience the fun and playfulness of engineering as a curricular alternative to memorization for the annual test [12], [13], [27].

What begins as a simple paper circuit created in the electric notebook, and eventually programming and robotics, is an enormous springboard to engineering complex robotics. More importantly, meaningful and creative experiential learning may draw more children into engineering and STEM fields. The bigger picture is systems thinking and how all of these seemingly separate theories, and ideas all relate and combine into a new way constructionist learning by developing a thinking child with the engineering mind that through the process of designing a simple circuit one day could design the next Mars rover.

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