A “Low-Floor” multimeter: supporting e-textile debugging by revealing voltage and continuity

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ABSTRACT

STEAM curriculums are widely implemented in K-12 schools, as part of the effort to promote computational thinking skills. This, together with increased accessibility of electronic components and kits, has opened the door for novices to engage in physical computing projects. Debugging these projects challenges students to learn and apply electrical concepts together with programming skills. Multimeter, the most common tool for measuring electric circuits, is placing a very high bar for novices to use. This paper presents a work in progress toward the development of a low-floor multimeter. The tool is designed to be used by high-school students with no prior electricity knowledge as part of their e-textile curricula. By providing students the opportunity to form a conceptual understanding of voltage and current flow, we hope to scaffold their exploration and debugging process in a meaningful way.

CCS CONCEPTS

• Computer Science Education • Computational Thinking • K-12 Education

KEYWORDS

Computer science education, e-textiles, debugging, tools

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1 Problem and Motivation

STEAM curriculums have become widespread in K-12 schools in order to promote computational thinking skills [17]. Many initiatives have been developed for designing and implementing construction kits, tools, and courses [9, 2, 11, 14, 16], involving software, hardware, and crafts. This type of hybrid, hands-on, project-based learning initiatives afford learner self-efficacy, problem-solving skills, intrinsic motivation and development of logic. However, in order to construct and debug their projects, students must learn and apply both programming and electronics concepts while developing an understanding of the relationship between them [3]. As many of the curriculums are taught in computer science classes, students learn the coding aspects of a project - practices, and tools -while the hardware aspects are omitted.

While experienced “makers” and professional electrical engineers constantly use tools in their design and debugging processes, students and novices are asked to execute the same tasks without being provided any of those tools or receiving any instruction for their use [3]. For many novices in the field of hardware and for students, debugging a circuit is more of a gamble than open-ended, knowledge-based exploration. The lack of knowledge, together with the absence of appropriate tools, leads to a long, tedious, and in many cases, frustrating process.

We present a “low-floor” multimeter, that does not require any prior electricity knowledge [13] and is designed to support high-school students in debugging E-textile hardware by displaying the “unseen” behavior of a circuit that is a result of the amount of voltage and current and the relationship between them.

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2 Background and Related Work

Hybrid curriculum- without hybrid tools

With the increased value placed on teaching computational thinking to students [5,17] comes the development of interdisciplinary curricula for K-12 computer science lessons.[14]. While the primary motivation behind these initiatives is to promote CS education and coding [15], students must also learn and perform design, electricity, and engineering skills. To facilitate students’ learning in these areas, Kafai et al. [2014] developed and implemented an e-textile debugging curriculum.

Unlike experienced “makers” or electrical engineers, high-school CS students are not introduced to any supportive prototyping tools when introduced to hardware (i.e., breadboard for iteration and multimeter for measuring), that they can use later in their exploration. According to Booth et al. [2016], in physical-digital projects, most task failures were due to circuit-related problems that participants could not identify and tried to fix by editing their code. Even though participants were given a multimeter as a tool to examine their hardware, only 1% of them used it.

Visualization of voltage and current

In order to debug a circuit, one must understand its building blocks. People with no electronics experience have struggled to draw hypotheses about what went wrong and how to test those hypotheses [3,8]. Furthermore, the lack of feedback related to voltage drops or current flow contributed to the lack of conceptual understanding among novices. Drew et al. [2016] showed how visualizing voltage on the breadboard helped both novices and experienced “makers” debug. Additionally, users who were asked to debug a circuit on a breadboard that can sense and display current reported that it helped them to form a conceptual understanding of electricity and thus to debug their circuits [5]. Studies that found the voltage and current visualization useful for users' construction and debugging process of physical computing projects, had integrated their system in a traditional breadboard [1, 6,12,18]. While this approach is applicable in many cases of circuit design, E-textile projects are exceptional in that sense. Soft-computing projects are usually planned by drawing on paper instead of on a breadboard and are then sewn into a piece of fabric [7,11].

The most common tool for measuring voltage and current is a multimeter. Booth et al. [2006] suggest that given the prevalence of circuitry bugs, it will be helpful to teach people how to use a multimeter in order to check for continuity or measure current. However, multimeters present a steep learning curve by requiring a basic conceptual understanding of electricity as users first have to come up with the idea as to why their circuit is not working [6] and then to set the multimeter to specific measurement to test their idea [10]. Therefore, multimeters, versatile as they may be, are not desirable among novices and CS educational settings.

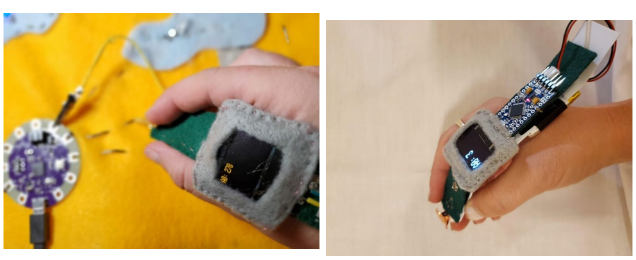

Figure 1: The "low-Floor" multimeter measures voltage and continuity in an E-textile circuit.

3 Approach and Uniqueness

Our device is a hand-held, low-floor multimeter that uses an OLED screen to display the voltage of a given point on a circuit. The hand-held tool is designed to close the gap between the steep learning curve of the existing multimeter as a measuring tool and the difficulty of forming an understanding of the physical computing mental model. The tool enables students to explore circuits and debug their e-textile projects by relying on its electrical properties- a fundamental element of physical computing. Our device has two main features that address common bugs [7,3,6] in circuit design:

- Continuity meter - measures current in a specific range. It can indicate shorts or breaks on a circuit.
- Voltage meter - measure the voltage at a specific point (i.e., component/pin/wire) in a circuit. It can indicate, for example, variables in a code that do not match circuit [7]. Probing pins on a microcontroller and using a common ground point will tell us which of pins are powered.

The device is equipped with two probes for measuring. One serves as ground point and the other as analog input. The device was designed to allow children to trace their e-textile wires and circuits in order to construct and scaffold their debugging process.

In a preliminary evaluation of the hand-tool usability, we conducted informal testing and observations in the context of debugging e-textile projects by students. Our preliminary feedback was positive, with users expressing their “aha!” moments. Potential users described their experiences as engaging and “educational” as a new knowledge had enabled them to explore further. While the tool allows “seeing” the circuit properties, a limitation arose regarding the numerical representation of the voltage as it was still confusing for students.

4 Contribution and Future work

We present the first iteration of a low-floor multimeter. Our debugging tool prototype presents an alternative for traditional debugging tools [3,5], like the multimeter, and an opportunity for a deeper understanding of circuitry and electricity for K-12 students with no prior electricity knowledge. In future work, we plan to test and integrate different types of feedback to help indicate current flow and voltage (e.g., graphic display of the voltage wave, sound, single LED). Furthermore, this device is part of a larger effort to design a full set of debugging tools for e-textiles; thus, it will be integrated with other tools such as desktop simulator and dedicated Arduino library.

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