Increasing STEM Interest through Coding with Microcontrollers

Sandra B. Nite
Department of Mathematics)
Texas A&M University
College Station, Texas USA
ORCID 0000-0002-0181-1150

Ali Bicer
School of Teacher Education
University of Wyoming
Laramie, Wyoming USA
abicer@uwyo.edu

Kimberly C. Currens
Teaching, Learning & Culture
Texas A&M University
College Station, Texas USA
currens1962@tamu.edu

Rayan Tejani
Allen Academy
Bryan, Texas USA
r.tejani@allenacademy.org

Abstract—*This research-to-practice full paper presents a study about capturing student interest in computer science. Constructing new knowledge through doing provides an effective pedagogy to increase interest in STEM fields. Coding has become increasingly more important in most career fields, STEM and non-STEM, as technology advances permeate every aspect of our lives. Summer camps offer informal learning opportunities that allow students to engage in STEM activities collaboratively. This study, using a microcircuit kit to introduce basic coding concepts, is seen through the lens of culture, cognition, and literacy. Common themes when defining culture include united standards, common past, shared linguistics, and collective behavior patterns. Cognition comprises knowing, remembering, and judging with the ultimate goal of problem-solving. The cognition of this informal learning experience focused on coding concepts as related to interacting with a microcircuit kit. Literacy, in general, is based on three components: print knowledge, phonological awareness, and oral language. STEM literacy is the ability to develop fluency in STEM such that an individual can express ideas plainly and persuasively, and challenge personal reasoning and thinking. The theoretical framework combines two ideas: 1) situated learning, from John Dewey's theory of experiential learning, and 2) pathways to STEM. Situated learning-based constructivism, occurs in social contexts where knowledge develops through experience, practice, and engagement. As learners develop meaning, competence, and knowledge, they construct identities through blending culture, cognition, and literacy. Recommendations for facilitating pathways to STEM careers include reducing STEM participation barriers for all students. Also recommended is incorporating technology, demonstrating relevance, using collaborative teamwork to cultivate social support systems, and hands-on activities with investigative learning. The research question was, "What effect did a summer camp experience that included microcontroller kits have on student knowledge of circuitry, microcontrollers, coding, and computing careers?" Rising 7th-12th grade students participated in a summer camp in the western part of the US. They engaged in four mini-courses, one of which was working with microcontroller kits. These kits required students to create circuits that performed actions such as flashing light, buzzers, and pitched sounds. Although some students created codes from scratch, most students downloaded and edited code to perform the various functions. Students (N = 30) completed a pretest and posttest to assess their knowledge of circuitry, microcontrollers, and coding. There were 19 males and 11 females in the study, with foster students, students with learning disabilities, and diverse ethnicities represented. A paired-sample t-test was conducted to determine whether the scores from pre and post were statistically significantly different. Hedge's g effect size was calculated. Mean scores from the pretest and posttest increased from 6.63 to 8.20 and were statistically significantly different (p = 0.018). Hedge's g effect size showed practical significance. Additionally, several students spent extra time at every opportunity, to use their microcontroller kits to expand or create additional projects.*

Keywords—*coding, microcontrollers, summer camp, computer science*

I. Introduction

The shortage of STEM majors and workers in the U.S. has been a concern for a number of years. In 2012, it was estimated that the U.S. was still short one million STEM workers and needed to increase the number of undergraduate STEM degree recipients by about 34% annually. For degrees earned in 2003-2004, 35% of students who began in a STEM field completed a STEM degree. Among those STEM majors, computer science was the lowest at 24% of the degrees [1].

A. *Coding for All*

Coding and computer science are becoming increasingly important and useful in a myriad of careers outside the usual STEM fields that use these skills. The importance of computer science is evident not only in the recommendations by the President's Council of Advisors on Science and Technology (PCAST) but also in the National Science Foundation (NSF) funding opportunities. Most general STEM initiatives include tracks for coding and computer science, but there are multiple requests for applications (RFP) such as STEM + Computing K-12 Education (C+STEM) and Computer Science for All (CSforAll) focused entirely on computer science. (See https://www.nsf.gov/funding/azindex.jsp?start=C).

B. *Theoretical Framework*

The theoretical framework for the study is based first on John Dewey's theory of situated, experiential learning. This type of learning occurs in social contexts, inside or outside classrooms, where knowledge develops through experience, practice, and engagement [2]. Thus, hands-on learning of real-life applications such as working with circuitry and microcontrollers, where students collaborate to complete the tasks, is an example of an experiential learning experience [3]. Often STEM summer camps have recognized the need for experiential learning or constructivism to maintain student focus and interest and as a more effective learning method than lecture and practice exercises [4, 5, 6]. Students in the camp for this study engaged in creating circuits to perform various tasks as shown in Table 2. Through these exercises, they constructed their own learning about circuitry. Camp instructors circulated, asking students to show and explain their circuits to help ensure that they were learning from the experience of creating the various circuits. The second theory from which our framework evolved is that of facilitating pathways to STEM. Recommendations include reducing barriers to STEM participation, especially for subpopulations underrepresented in STEM, including women and minorities [7]. Most of the students in this study were provided partial or full scholarships to allow them to participate in the summer camp, thus reducing one barrier to STEM participation. Foster students and students with learning disabilities were also included in the participants. Incorporating technology, demonstrating relevance, and using collaborative teamwork are ways to reduce additional STEM barriers [8]. The educational process in STEM as well as other areas encompasses culture, cognition, and literacy as partners in learning. Teachers provide a certain classroom culture for students to learn [9]. With experiential learning, students need a culture of acceptance and of expectation that the problem-solving process involves failure and redesign as part of learning. Cognition is an essential element in the learning process that occurs in the brain when students know, remember, and evaluate the processes and outcomes of their learning experiences [10]. Literacy originally referred to reading and writing abilities, and was considered a crucial precursor to academic accomplishment [11]. Literacy has been applied to other educational contexts, such as computers. As technology has become more ingrained into our everyday lives, it has become apparent that a certain competency with computers is very important. Thus, for some time now efforts have been made to distinguish and define computer literacy situated in our world today [12]. The summer camp activities with coding and microcontrollers provided an opportunity for students to engage in hands-on learning in an informal classroom setting and engage with their peers as they learned to create circuits and edit and create code to use those circuits to perform tasks such as flashing light, buzzers, and digital musical pitches that are used in many technological applications in their daily lives. Students' interest was piqued because they experience flashing lights and buzzers every day, but now they had a chance to create them and understand how they worked. They were also given the choice to expand their projects further with their own ideas, as explained and illustrated in the results.

C. *Background on STEMS Camps that include Coding*

Summer STEM camps have been one of the responses to the need to engage students in STEM experiences that could increase their interest in engineering and other STEM studies and careers. In recent years the technology piece of STEM in the form of coding has moved to the forefront of many efforts. Some camps, such as the one in this study, have a goal of providing several different STEM experiences, with coding being one of those [13, 14, 15]. Other camps have focused on only one topic, such as robotics, 3D design, astronomy, aerospace engineering, or coding. Coding camps have slightly different approaches and perspectives, although they all focus on increasing student content knowledge and interest in computer science. Very few actually measure the increase in content knowledge, but most use surveys for student self-assessment of knowledge and/or STEM interest [4, 6, 14, 15, 16, 17, 18, 19].

Coding camps have taken somewhat different approaches to engage and interest students. Appealing to students' personal relevance with projects has been the hook for some coding camps [5]. Research that shows students, including those most underrepresented in engineering, are attracted by contributions to social issues has influenced coding camps to try to appeal to students from that perspective [4, 6, 16, 19].

D. *Research Question*

The research question for the study was "What effect did a summer camp experience that included microcontroller kits have on student knowledge of circuitry, microcontrollers, coding, and computing careers?"

II. METHODOLOGY

A. *Summer Camp Description*

Secondary school students attended a one-week summer STEM camp (N = 46) on one of two university campuses in the western U.S. Scholarships were provided to many students, allowing the camps to serve underrepresented populations in STEM. Students applied for the camp, but the only requirement was to provide evidence that they were rising 7th – 12th graders, for one university, and aged 14-21 secondary students as required by the funder in the other camp. Table 1 shows the demographic make-up of the students. In addition, at least 5 foster students and 3 additional students with disabilities were served. IRB approval was obtained for the testing. Students completed the test online before instruction began the first day of the 5-day camp and again at the end of instruction of the last day of camp.

TABLE I. GENDER AND ETHNICITY

Race/ Ethnicity	**Gender**	
	Female	***Male***
White	9	15
Hispanic	5	7
Asian	4	4
African American	0	2
TOTAL	18	28

One of the four mini-courses each day was working with Arduino-based microcontroller kits. Each day's agenda involved circuitry and/or coding activities to accomplish tasks and learn definitions and concepts in circuitry and coding. Table II lists some of the tasks and concepts addressed each day. Students worked through lessons at their own pace, with instructors circulating to ask and answer questions about the concepts and processes students followed and to help students trouble-shoot any issues in their circuitry or code. As they circulated, instructors asked students to explain concepts to ensure they were not following circuitry instructions without learning concepts.

TABLE II. MICROCONTROLLER LESSONS

Day	Tasks	Concepts
1	Light up LED Vary LED color Create RGB night light	polarity, Ohm's Law, analog vs. digital
2	Activate buzzer Create a tune Call/Response Game	arrays, resistors, for loops, measuring elapsed time
3	Create a motion alarm Code distance sensor	digital sensors, servo mechanisms
4	Create LCD displays Code temperature sensor	pixels, algorithms, strings, pointers
5	Use motor to create robot	input voltage, integrated circuits, autonomous vehicles

B. *Instrument and Analyses*

Researchers created a 15-question pre/post-test to assess student basic knowledge about microcontrollers and coding (see Appendix). Questions were related to concepts addressed in the microcontroller lessons. Pre- and post-test means and standard deviations were calculated to see whether there was an improvement in knowledge. Some students only attended four days, missing the first or last day of the camp, and a few that were present failed to complete the pre- or post-test. A paired samples t-test was conducted ($N = 30$) for the complete sets of scores rather than imputing values. Hedge's g effect size was calculated.

C. RESULTS

Analysis of the pre/posttest responses through an independent samples t-test (not paired) using the scores from all 46 students revealed that the students increased in knowledge of circuitry, microcontrollers, coding, and computer careers overall.

Table III shows the means and standard deviations from the pretest and posttest. The paired samples t-test yielded a test statistic of 2.508 ($p = .02$), showing a statistically significant difference in scores before and after the microcontroller experience. The Hedge's g effect size for this difference was 0.47, and the confidence interval associated with this effect size was (-0.04, 0.98). This shows a practical significance because educational interventions rarely yield high effect sizes, and positive changes show that the intervention could be impactful over time. Fig. 1 illustrates the means and confidence intervals for the pre- and post-tests scores. See the Appendix for the questions on the pre/post-test.

TABLE III. MEANS AND STANDARD DEVIATIONS

	Pretest	Posttest
Mean Score	6.63	8.20
Standard Deviation	2.82	3.71

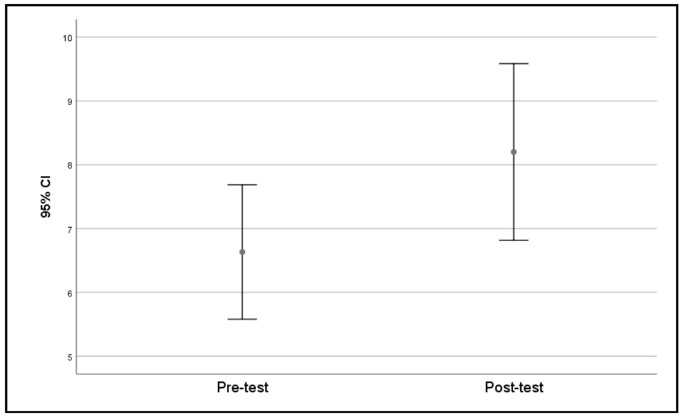

Fig. 1. Pre-test and post-test scores

The results of individual questions on the pre/post-test were examined to see where students had the greatest gains in knowledge. The four questions with the greatest gains were two questions about the use of microcontrollers in the real world, a question about characteristics of a potentiometer, and a question about the colors of light than can be produced with an RGB LED. Table IV gives the percentage of students who answered each question correctly on each test.

TABLE IV. PRE- AND POST-TEST PERCENTAGES CORRECT

Question Number	Pretest % Correct	Posttest % Correct
1	77	70
2	57	80
3	57	60
4	20	30
5	57	73
6	40	40
7	27	50
8	33	43
9	27	57
10	37	47
11	57	67
12	43	43
13	40	63
13	60	57
14	40	63
15	33	40

Fig. 3 shows a student working with her circuits on her microcontroller kit. Students were allowed to create their own designs when they finished the required lesson and had remaining time. The students in Fig. 2 were fascinated by the 3D printer and wanted to create a time-lapse video of the print process. They taped a cell phone to the front of the 3D printer, but after a period of time, the light went out in the printer. Thus, they began the design process to use the microcontroller kit components to achieve their goal. They calculated how often the light went out on the printer and tried to use a timer to turn it back on. That did not work very well, so they redesigned. In the final design that worked, they put a light sensor inside the printer and taped a switch arm next to the button on the outside of the 3D printer. When the light went out, the light sensor then caused the arm to hit the button that turned the light back on.

Fig. 2. Students creating time-lapse video using a microcontroller.

Fig. 3. Student working on microcontroller circuitry.

A student who was particularly interested in the microcontroller lesson on sound wanted more than the three notes programmed with the three buttons in the kit. He programmed his circuit so that he could make a quick change to move the notes up to the next set of notes. The instructors loaned him buttons from the extra kit, and he programmed his microcontroller to be able to play two octaves (15 notes). This opportunity to work with microcontrollers showed students the myriad of applications of microcontrollers possible.

The examples of students who used their knowledge in new situations of their choosing illustrate the culture of the camp that encouraged students to explore deeper the areas of interest in the camp. When they completed the required circuits and coding, they were allowed to work on something of interest, and instructors encouraged them and gave them suggestions to try when needed.

D. Discussion

The main purpose of this study was to explore the effects of an Arduino-based coding/microcontroller intervention on middle and high school students' knowledge related to electricity. The findings revealed that students developed their electricity knowledge statistically significantly after participating in microcontroller and coding activities in a STEM summer camp. This result is consistent with that of a previous study, in which researchers found that students who participated in microcontroller and coding informal activities improved their motivation towards STEM majors and careers [20]. However, there were no studies found that focused on how students' specific knowledge (e.g., electricity) changed after they received a microcontroller and coding intervention. Therefore, this study is timely to address this gap by revealing the positive effects of informal microcontroller and coding activities on middle and high school students' knowledge related to the concept of electricity. This result can be explained by the fact that students' learning of abstract science-related concepts can be fostered through applying tangible objects [21, 22]. Since students often do not make direct observations of the electricity-related concepts in daily life, applying microcontroller and coding projects through the Arduino tool made their learning meaningful. For example, students observed how and why the street lights come on at night but not during the day, based on the level of lights coming to the light sensor. The most essential part of these projects is allowing students to construct all the circuits from scratch, writing coding, and making changes on the coding to observe how different variables and concepts are related to each other. Our findings and explanations can be supported by Confucius' well-known quote that, "I hear and I forget. I see and I remember. I do and I do understand." Students in this project had opportunities to learn the concepts through setting up mini-projects and writing codes to observe how to transfer data from computer to microcontroller as opposed to many traditional classrooms in which students primarily memorize the scientific concepts and not provided with extensive opportunities to practice these concepts through tangible objects. Developing students' knowledge in STEM-related concepts (e.g., electricity, coding) through enabling them to apply hands-on projects may also develop their interest in computer engineering majors and careers. This can be explained by Bandura's socio-cognitive theory, in which he noted that learning occurs in a social context with a dynamic interaction of the person, environment, and behavior [23]. Because students who received the intervention actively collaborating with others to set up their projects as active members of their assigned groups. They learned through observing and discussing the circuitry with each other. They corrected their own or group members' mistakes and misconceptions through communicating with others. In general, the implications of implementing coding to communicate through microcontrollers with middle and high school students can advance their knowledge related to electricity and coding concepts, and this may lead them later to follow engineering majors and careers when they are more confident in their circuitry background knowledge.

The use of microcontroller kits for circuitry and coding can be very beneficial and effective in increasing student knowledge about career opportunities and pathways involving computer science. The advancement of opportunities for students to engage in these activities in formal and informal venues can engage students in ways that further their knowledge and interest. The camp experience in this study showed researchers and instructors how much students learned and enjoyed the experiences. Many students expressed their surprise at what they learned and how much they enjoyed it, especially some whose parents sent them to camp even though they were not initially particularly interested in coming to the camp. Culture, cognition, and literacy combined to provide a flexible learning experience for students. The culture set by instructors allowed students to design and solve their own microcontroller problems and projects, based on the literacy and cognition provided through the required circuitry and coding lessons. Students worked collaboratively with microcontroller kits and coding with computers. Most students paid little to nothing for the camp experience, and the funding provided allowed students underrepresented in STEM, including foster children, to participate in experiences not often available to them.

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Appendix. Microcontroller Test

1. A MICROCONTROLLER

is a small portable computer.
takes inputs and interprets the information to control outputs.
relates electronics to the physical world.
All of the above are true.
None of the above are true.

2. MICROCONTROLLERS ARE USED IN WHICH OF THE FOLLOWING?

measuring pollution in a stream
timers in a microwave
heart pacemakers
all of the above
one of the above

3. WHICH OF THE FOLLOWING IS NOT TRUE OF LEDS?

LEDs are lights made from silicon dioxide.
LEDs have a positive and a negative leg.
LEDs only let electricity flow in one direction.
LEDs have a built-in resistor.

4. RESISTORS

are marked by strength in volts.
increase the flow of electricity.
restrict the ohms in a current
contain colored bands to represent numbers.

5. WHICH OF THE FOLLOWING HAS POLARITY?

LED
resistor
potentiometer
photo resistor

6. COLORED PLASTIC COVERING WIRES INDICATES WHETHER THAT WIRE CAN BE USED FOR POWER OR FOR GROUND.
True
False

7. WHICH OF THE FOLLOWING IS NOT TRUE ABOUT A POTENTIOMETER?

It is a resistor.
It can adjust sound volume.
It is polarized.
All the statements are true.

8. DIGITAL SIGNALS ARE MADE OF AN INFINITE NUMBER OF VALUES.

True
False

9. An RGB LED can only show red, green, or blue light.

True
False

10. Which of the following is NOT true of buttons?

They only remain on while they are pressed.
They differ in color based on how they behave.
They can be used to reset something.
They are not polarized.

11. Else If statement

are the same as nested If statements.
repeat a section of code a set number of times.
determine which section of code to run based on the truth of a statement.
can only run one logic test per statement.

12. A For loop

repeats a section of code a set number of times.
utilizes a counter.
uses the letter i as a variable.
all of the above.

13. Which of the following is NOT true of an ultrasonic distance sensor?

It measures distance using sound waves.
It senses the presence of an object.
By law, it cannot use lasers.
It can be used to calculate speed and acceleration.

14. LCDs

can show letters and numbers.
are dangerous for use in watches.
do not work well in calculators.
have a fixed brightness that only changes when the LCD is burning out.

15. Which of the following are NOT polarized?

batteries
buttons
buzzers
All of the above are polarized.