AC 2010-2272: DESIGNING AND IMPLEMENTING CHAIN REACTIONS: A STUDY OF SEVENTH-GRADE STUDENTS' KNOWLEDGE OF ELECTRICAL CIRCUITS

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Designing and Implementing Chain Reactions: A Study of Seventh-grade Students' Knowledge of Electrical Circuits

Abstract

This paper describes the implementation and results from the study of a novel teaching and learning experience in K-12 Engineering Education. The specific novel teaching and learning experience focused on a Chain Reaction/Circuits thematic unit. The thematic unit was embedded in a National Science Foundation (NSF) sponsored Information Technology Experiences for Students and Teachers (ITEST) project. The project served over 100 students via a highly engaging after-school engineering education program in four middle schools from traditionally under-represented populations.

Seventh-grade students were engaged with the idea of designing a chain reaction after watching the "Cog" a 2003, Honda commercial. Notions of chain reactions such as local actions having global impact were discussed. Students were provided with a variety of technology tools beginning with components for creating a simple circuit (switches, electrical cables, an light emitting diode-LED, buzzers, and a battery pack) and household objects (cardboard, coat hangers, aluminum foil, milk/juice cartons, etc). Students investigated different combinations of the electrical components creating varying types of circuits, progressing to constructing their own homemade switches from the household objects. PICO Cricket kits were introduced and students used the PICO software to program and design intelligent reactions to mechanical actions. Continuing with the PICO Cricket Kits students constructed creations (autonomous art installations) that would respond to stimuli from their surroundings (e.g., sound, movement, touch, and light). Individual and class discussions fortified the relationships between inputs/outputs and chain reactions. Ultimately, the entire cohort engaged in the creation and execution of a large-scale chain reaction (Rube Goldberg Machine). Students were placed into groups of two and given one table. Each group (thus, each table) was connected through wood blocks, when touched would fall into the next wood block, acting as both the group's table input and table output.

Student learning was assessed[1,2,3] through formal and informal methods. Informal assessments consisted of open-ended questioning, demonstrations, teacher observations, and student constructions. Formal assessments consisted of pre- and post-assessments specific to unit content. Analysis of formal assessments utilized two sample dependent t-tests to determine if significant differences existed across pre- and post-assessments. Analysis showed a statistically significant difference between the means for the pre and post assessments; $t(74) = 8.75, p < .01$, *Effect Size* $= 1.13$. Suggesting a potential to enhance learning when we engage youth in experiences that emphasize both utilitarian and inquiry-based motivations.

Introduction

The purpose of this paper is to describe the participants, activities, and accomplishments of a chain reaction/circuits thematic unit delivered during an after-school program. Fundamental differences between formal in-school[4] and informal[5] after-school settings preclude us from making any claims to the validity of such a program in the formal school setting. We leave it to the reader to decide which aspects of the unit can be successfully transferred to the classroom. As a group of educators and researchers, our primary goal was to investigate student learning related to a project-based, hands-on curriculum designed to focus on student inquiry and discovery in the informal learning setting. This NSF sponsored ITEST project known as "Learning through Engineering Design" was delivered to meet ITEST program guidelines. The primary goal was to engage middle school youth in hands-on inquiry based learning experiences in a informal-learning setting designed to enhance student learning in the science, technology, engineering, and mathematics (STEM) fields.

Program Activities

Even though this paper is primarily focused on studying seventh-grade students' knowledge of electrical circuits in the context of designing and implementing chain reactions, we feel that the reader should be aware of the overall project so he/she will have a context for the reported activities. Activities were organized into school year activities and summer activities, thereby effectively providing year-round programming. Activities were offered for 78 contact hours during the academic year and 48 contact hours during the summer; each year of the two-year student experience. Units delivered throughout the academic years include:

1. The Desert Tortoise: Study desert tortoise behaviors and habitats and build a toy robot that behaves like a desert tortoise using LEGO Mindstorms NXT robotics kits.
2. Circuits/Chain Reaction: Study systems concepts (e.g., inputs, outputs, power supply), actions, reactions, and closed systems by building chain-reactions using electrical circuits, Pico Crickets, and found objects.
3. Urban Heat Island: Study the heat island phenomenon and build models to mitigate heat.
4. Exploring Mars: Study the surface of Mars, getting to Mars, exploring Mars, and living on Mars.

Units delivered during the two summers comprised:

1. Youth-Docentship: Study science and engineering phenomenon at the Arizona Science Center. Demonstrate knowledge gained throughout this year-round program by engaging younger peers and their families visiting the center through small-scale hands-on workshops on specific project-based challenges.
2. Industry-Internship: Study alternative energy sources (wind, solar, hydro, and hydrogen fuel-cells) and build renewable energy models at the Salt River Project, a local water and energy service provider.
3. Technology Workshop: Study basic TI-84 plus graphing calculator functions (graphing, creating tables, performing calculations, etc.) and its connection to basic programming, data collection probes (temperature, ultra-violet ray, moisture, acceleration, pH, and light), and the CBR2 a device that has sonic motion detector capabilities.

Students and parents attended four family nights per year. These family nights were designed to give students an opportunity to share their completed projects and learning with family members, school administrators, teachers, and peers.

Teachers

At each of the project sites, two teachers were identified to serve as after-school program facilitators. The principal investigator, the school district liaison to the project, and the school administrator met with interested teachers individually and selected two project facilitators for each site. Criteria for selection included expressed interest in the project curricula, curiosity and enthusiasm to explore new ideas and content, and availability for the duration of the year-round project. Teachers received a $3,000 stipend and seven professional development days when the district paid for a substitute teacher to work in the teacher's regular classroom.

Project Team

The project team included nine university researchers and faculty with expertise in the areas of engineering (Materials Science and Engineering, Industrial Engineering, Computer Science and Engineering), sustainability, science education, mathematics education, earth and space science, geology, counseling psychology, instructional technology, and education research methods. Project staff included: a) a female science educator with a masters degree in education and 14-years of experience teaching in high school settings and in a community college; b) a male graduate research associate with a bachelor's degree in mechanical engineering and a master's degree in mathematics education who worked part-time as a high school mathematics teacher while also enrolled in a doctoral program in mathematics education; c) a female teacher with ten-years of experience working with women in science and engineering who was also enrolled part-time in a master's degree in bio-engineering. In addition, six undergraduate research interns representing these engineering disciplines worked to help facilitate the project: Electrical and Electronics Engineering (female, Latino), Chemical Engineering (female, African American), Mechanical and Aerospace Engineering (1 female, White; 1 male, African American), Computer Science and Engineering (male, White), and Materials Science and Engineering (male, White). These undergraduate research interns served as peer-mentors and worked side by side with the participants and shared their educational pathways to their chosen field.

Participants

Table 1. Participants by Gender

	Number		
Gender	Year 1	Year 2	Percent
Female	32	35	58%
Male	16	33	42%
Total	48	68	

Table 2. Participants by Ethnicity

Ethnicity	Number Year 1	Year 2	Percent
African American	5	0	4%
Asian American	2	0	2%
Caucasian	12	21	28%
Hispanic	25	46	61%
Indian American	4	1	4%
Total	48	68	

The ITEST project spanned three years and included four junior high schools from a large district in the Southwest. During the first year two seventh grade cohorts in two junior high schools were selected utilizing a purposeful selection strategy. During the second year we selected two additional seventh grade cohorts from two different junior high schools in the same district. Participant demographics are provided in Tables 1 and 2.

The Circuits and Switches, Chain Reactions, and PICO Cricket Creations Unit

This unit was separated into three distinct activities: circuits & switches, chain reaction, and PICO Cricket creations. Each lesson was designed and implemented using the 5E learning cycle[6,7,8,9] (Engage, Explore, Explain, Elaborate, and Evaluate).

Circuits and Switches

The activity began with facilitators demonstrating objects with simple circuits (e.g. stopwatch, board game buzzer, the lights in the room, etc.). For the exploration phase students were separated into teams of two and given a bag of components (battery, buzzer, LED unit, 6volt light bulb, switches, motor, and wires). Each team was instructed to explore and play with the components. Upon completion of this exploration, students were again brought together to share insights and discoveries. Some ideas that emerged included:

- Circuits will not work if there are gaps.
- LED units only works when connected a certain way.
- Circuits can have more than one component at a time.
- Switches are different and require specific connections.
- Light bulbs in a circuit will dim when you connect multiple components in the circuit.
- Circuits with too many components will not work.

The interactive discussion continued until each question/idea was discussed and possible reasons were examined. We expanded on the exploration and class discussion by demonstrating how to complete a simple circuit using the light bulb, then the motor, etc., simultaneously introducing vocabulary like *input*, *output*, and *power supply*. Upon completion of the expand phase, students were given ten minutes to continue exploring the components on there own. We used this time to informally probe student understanding. Once we were satisfied that students had a working knowledge of simple electrical circuits, we proceeded to construct homemade switches. For this activity students were challenged to create a switch using construction materials and household objects (aluminum foil, tape, paper, fabric, straws, etc.). Students were given leeway to create any type of switch and as many switches as they wanted. To evaluate their switches and overall understanding, students used their switches and the components to create various circuits.

Chain Reactions

The chain reaction activity began by engaging students with an introduction to a chain reaction as portrayed in the "Cog" a 2003, Honda commercial. The "Cog" sequence begins with a transmission bearing rolling into a synchro-hub, which then triggers a series of movements with other parts of a Honda Accord. For instance, windscreen wipers 'walk' across the floor, valves roll down the hood, and carefully weighted tires roll uphill. The commercial ends when the power door locks on a complete Honda Accord are activated. After watching the commercial several times, facilitators lead a class discussion exploring the chain reaction concept. The facilitator made a point to introduce notions of chain reactions as local actions having global impact that resulted in whole group discussion. When the discussion was at a stopping point, facilitators explained the unit challenge: to construct their own chain reaction. With the challenge set, the students were formed into teams of two and given time to explore and research chain reactions through the media of their choice. Upon completion of the explore/research phase students were brought together to participate in a group share activity that allowed each team a chance to explain their findings. During the group share activity project facilitators elaborated on topics where appropriate, to include informal questioning concerning topics that were deemed important, but not reported in the group share activity. The evaluation phase consisted of each team completing the challenge (to build a chain reaction).

Each team was assigned a designated workspace consisting of rectangular tables. Facilitators pushed the tables together lengthwise to form a collective serpentine workspace. Each group was given two wood blocks and access to a collection of construction materials and household objects (e.g., marbles, string, straws, tape, cups). The specification of the challenge stated that the wood blocks must be the input and the output for each team's chain reaction. In essence the motion of the input wood block tipping over must start a team's chain reaction, eventually resulting in the table's chain reaction toppling the output wood block into the input wood block of the next team. While students were engaged in creating their chain reactions, other chain reaction videos were constantly looped and displayed in the background. To successfully construct individual chain reactions, teams progressed through iterative design, build, and test phases. Once each team had constructed and tested successful chain reactions, all the chain reactions were connected together and the whole class chain reaction was started. The first table's input wood block was toppled and the "class" chain reaction began. Each cohort created different and complex chain reactions. Two of the four cohorts ran their chain reactions through without any complications on the first attempt, while the other two cohorts hit a snag here or there. In either case the students insisted they run their chain reactions two, three, and even four more times representing their interest in making design changes.

PICO Cricket Creations

This experience was initiated by a class discussion engaging the students to brainstorm what they had learned about simple circuits, components, and switches in previous units. We continued this brainstorming session by discussing ways in which simple circuits, components, and switches are used in our lives. By introducing applications we were able to increase the complexity of the conversation from simple circuits, components, and switches to systems of design for specific purposes. With this new idea we were able to introduce sensors and how they are used to interpret the physical world. Students were separated into teams of two and given a PICO

Cricket[1] kit to explore. The Pico Cricket kit is a construction kit[10] that provides students with robotics-based tools to design, build, and test their own creations. Given a sufficient amount of time to explore, students were brought together and engaged in a group share activity, where each group was given an opportunity to share what they had learned. During the group share activity, project facilitators elaborated on specific components and actions overlooked in the exploration phase such as understanding the workings of a touch sensor. Exploration continued by investigating the PICO Cricket software. Each team was given access to a computer with the software and instructed to play and explore. At this time students were free to investigate the software features as they saw fit. After students had exhausted their exploration time facilitators held a class discussion allowing students to report what they had learned. The elaboration phase for the software portion involved a slightly more structured approach. Students were given mini-programming tasks. The programming tasks were designed to scaffold student learning through basic software operations. An example of the tasks (with program solution) is shown below.

Programming Task
Start the program with the touch sensor: display a red light for 1 second, then a blue light for 1 second, then a green light for 1 second, turn off the light, then chirp.

Solution

Figure 1. Sample programming task with solution.

The evaluation phase consisted of each team designing and building a PICO Cricket Creation. The specifications of the challenge stated that each creation must include at least one sensor, at least one output, and fulfill a purpose. The evaluation phase of *The PICO Cricket Creations* activity consisted of each team completing the challenge. Through the creation of a physical object, participants were able to monitor their success in meeting the challenge. Students engaged in making iterative design changes and tested their changes until they were satisfied with the outcome. For instance, one team used a light sensor to trigger action in their creation and they adjusted the design and related programming until the action would begin when the light sensor was covered by a student's hand. This was an exercise where students had to adjust the sensitivity of the light sensor in the programming phase to meet their desired response.

[1] The Pico-Cricket kits is a product of the Playful Invention Company. Each kit contains a motor, display, colored LED lights, speaker, touch sensor, light sensor, sound sensor, resistance sensor, control unit, and programming software.

Data Analysis

Student learning was assessed[1] using formal and informal methods. Formal assessments consisted of pre- and post-assessments. Informal assessments consisted of open-ended questioning, demonstrations, teacher observations, and student constructions. These were used to guide daily activities and lessons. Student constructions included chain reactions, switches, circuits, and PICO Cricket Creations. The informal analysis discussion for this paper will focus on the PICO Cricket Creations.

Informal Assessments

Students were asked to describe the operations of their PICO Cricket Creations. Examples of student descriptions and the resultant programming for the creation appear in Figures 2 and 3.

Team 1

When you press the touch sensor button, a number between 1-500 will be displayed and the cricket will play a tune. When the song is finished, a rooster will crow and the sound box will play Beethoven's Ode to Joy. The motor will spin a white foam ball, and the person will swing. Give the person a push to make it spin all the way around. Once the song is finished and the motor has turned off, the sound box will clap three times and the cricket will chirp. The pattern will repeat until you turn it off.

Program

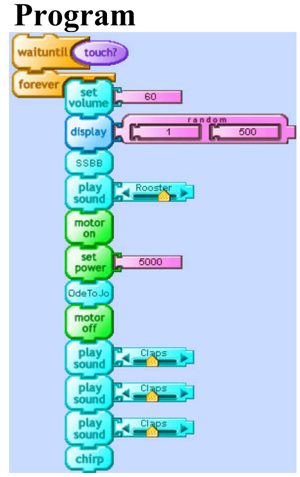

Figure 2. Musical Swing

Team 2

We want to show you how to work our system. When you push the big white button, be ready! It will start playing a song and two lights will change from dark blue, to light blue, then a bright purple. The lights will blink and it will play "La Cuca". After the song is finished, our bells will spin around. Push the big white button to stop the spinning.

Program

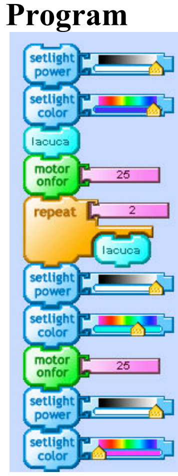

Figure 3. Spinning Bells

We draw the reader's attention to the temporal nature of these examples. The presentation of these examples suggests that students were merely describing the actions portrayed by the attached program. However, students were challenged to construct a PICO Cricket Creation of their own choosing. In all instances a basic program did not exist, which forced students to conceptualize desired actions and translate those into the computer program. The presence of a working PICO Cricket Creation and its correlation to the desired outcome demonstrates the success of each group.

Formal Assessments
Pre- and post-assessments in the form of four open-ended and fill-in-the-blank questions relating to major unit content were administered (Appendix A). Questions ranged from identifying components, to completing a simple circuit diagram. A rubric (Appendix B) was used to score the pre- and post-assessments. A paired-sample dependent t-test was used to investigate the statistical significance of the scores, while the effect size was determined by dividing the mean difference by the average standard deviation between pre- and post- scores. The resulting statistics are shown in Table 3.

Table 3. Pre-Post Assessment Statistics

n=75	Mean	SD	Mean Difference	T	P	Effect Size
Pre-Assessment	30.67	16.12	17.33	8.75	< .001	1.13
Post-Assessment	48	14.57				

Statistical analysis shows a statistically significant difference between the means for the pre- and post-assessments; $t(74) = 8.75, p < .01$. Students had not previously engaged in the topics associated with this unit and as a result they experienced high levels of learning. The results indicate that the technologically centered, hands-on learning experiences had a statistically significant impact on average student learning as measured by the pre- and post- assessments. The standard deviation decreases from pre- to pos-assessment, indicating average learning as a group, rather than exceptional gains by a few and low to stagnant (or negative gains) by the majority. The effect size is large at 1.13, suggesting an average increase of a little more than one standard deviation from the pre-assessment mean.

Educational Importance of the Study

The logical and organizational thinking involved in computer programming is complex and sophisticated. By utilizing a hands-on, project-based approach[11,12,13] we were able to introduce and help cultivate these complex notions. By structuring the unit through project challenges, students were given opportunities to:

- Assess their own learning and monitor their success[14]. This is a key characteristic of *metacognition*[2] and helps students transfer knowledge to different contexts.
- Broaden the content in which they constructed their knowledge[15] through the diversity and exploratory freedom allowed of the challenges.
- Construct an end product that served as physical evidence[1] of their learning.

Students who find traditional in-school science and math curricula uninteresting and disconnected from their lived-experiences need to be engaged in learning by doing[16]. The critical

[2] Researchers refer to one's ability to predict their performance and monitor their level of understanding as metacognition[1] – *"A metacognitive approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them".*

issue for our nation is to enthuse all youth, particularly, traditionally under-represented students: *females and ethnic minorities*, in STEM subjects. Results from this study will be useful for others who are interested in informal learning strategies and studying the impact of such efforts.

Note

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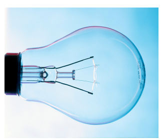
Appendix A

Circuit Pre- and Post- Assessment

1. A friend of yours wants to learn about circuits. To help, list four characteristics of an electrical circuit?

2. Your friend is confused about inputs, outputs, and power supplies. To help, label each diagram as an input, an output, or a power supply.


Batteries


Light Bulb

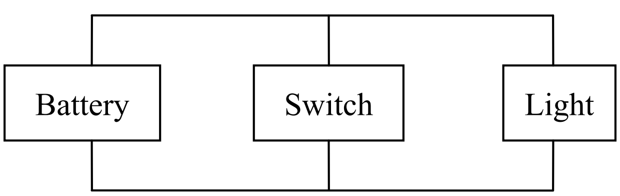

Light Switch


Microphone


Speakers

3. Your friend heard her teacher talking about electrical switches and wants to know more about them. Describe the function of a switch in an electrical circuit (i.e., what does a switch do).

4. Now that your friend understands electrical circuits he/she drew two circuits. Look at each circuit and identify if the circuit is wired correctly. If the circuit is wired correctly write "yes" if the circuit is not wired correctly write "no". If the diagram is wired incorrectly draw your own diagram showing your friend how the circuit should be wired.



Appendix B

Circuit Assessment Rubric

Question 1: What are four characteristics of an electrical circuit?

0	1	2	3	4
-No Answer -Whole answer is incorrect.	One of the following: 1) Power supply 2) Output 3) Input, switch, or wires. 4) Must be closed	Two of the following: 1) Power supply 2) Output 3) Input, switch, or wires. 4) Must be closed	Three of the following: 1) Power supply 2) Output 3) Input, switch, or wires. 4) Must be closed	All of the following: 1) Power supply 2) Output 3) Input, switch, or wires. 4) Must be closed

Question 2: One point for each correct answer.

Question 3: Describe the function of a switch in an electrical circuit.

Group A	- Turns something on - Turns something off	- Makes something work		
Group B	- Completes a circuit - Allows power to "flow"	- Allows electricity to "flow" - Allows current to "flow"		
Group C	- Input - Output	- Power Supply - Current		
Score 1				
0	**1**	**2**	**3**	**4**
-No Answer -Entire answer is incorrect.	(1-2) in A/B/C	(3-4) in A/B/C	(5-6) in A/B/C	(7-11) in A/B/C
Score 2				
0	**1**	**2**	**3**	**4**
0 in C	1 in C	2 in C	3 in C	4 in C

Question 4: One point for each correct answer and one point for the corrected drawing for 4a.