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Board 67: Work in Progress: STEM Experiences Designed for STEM Constituents

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Work-in-Progress: STEM Experiences Designed for STEM Constituents

Introduction

This paper discusses structured engineering project activities to engage the following STEM constituents (a) students (b) educators (c) first-year engineering students in undergraduate degree programs. Laboratory and engineering project experiences can effectively introduce and reinforce STEM-related concepts. The first two constituents form part of the K-12 STEM education process. The third constituent represents the graduates of the process. The constituents identified as students are introduced to aspects of engineering design, assembly, test, and validation through step-based project activities. The introduction takes place with the students either participating in project activities in the undergraduate engineering laboratory or with faculty from undergraduate engineering programs traveling to the schools to (a) demonstrate engineering projects, and (b) engage the students in the engineering project activities. The typical duration of each session is sixty minutes. However, while it should be determined by the grade level of the students, on occasion this time has been shortened for lower grades to about forty minutes to align the session with the class period at the school. The survey completed by the students in grade four, grade seven, grade eight, and grade nine at four different schools reveal that at least 70% of the students rated the project activities with a score greater than 3.5 on a scale of 5. Most students expected the session to be longer and more frequent during the school year. Some recommended the inclusion of competition in the project design process.

The constituents identified as educators are engaged in structured project activities using the workshop setting. The project activities range from simple resistive circuit configurations to advanced transistor and RF circuits. Through participation in the workshop, the educators can identify opportunities to revise or incorporate new laboratory activities within their curriculum. Through these activities, educators can introduce and teach students the ability to use engineering technology to solve engineering problems. The workshop provides (a) an overview of the necessary and sufficient detail of concepts that would apply to the chosen project activities (b) application of these concepts through project-based laboratory activities. The participants are not required to or expected to know advanced concepts in circuits and electronics. The workshop provides the experiences necessary to link the theory to practice through assembly of the electronic circuit and experimental observations.

The constituents in the category of first-year engineering students participate in electrical and computer engineering (ECE) laboratory activities as part of the critical entry-level course, *First-Year Seminar in Engineering*. The duration of the session is fifty-five minutes or one class period. The ECE activities comprise the assembly, test, and validation of the (a) electronic timer circuit, and (b) digital logic gate circuits. The students use electronic circuit assembly kits which consume less time for the assembly and allow the students to focus more on the purpose of their actions, the capture, and interpretation of the desired outcomes.

Section 1 overviews the importance of STEM in the context of the constituents. Section 2 details the STEM project activities for each constituent. Section 3 documents the survey-based assessment provided by the constituents. What’s Next? appears in Section 4 and conclusions in Section 5.

Section 1: Importance of STEM

The high drop-out rates of students from the STEM school systems, the low enrollment of school graduates in the STEM colleges and universities across the U.S., and the lack of interest and motivation of undergraduate students to pursue STEM engineering disciplines can be attributed to (a) lack of awareness of the STEM-related careers after graduation (b) failure of the STEM curriculum to inspire the students to develop the life-long passion for STEM learning (c) inadequate preparation and lack of resources for the educators to effectively deliver STEM teaching.

Laboratory and project-based experiences delivered through outreach and partnership [1]-[9] between the engineering departments at Universities and the STEM schools can exploit the synergy [10] between the two environments. In addition, the emphasis on structured, consistent, and constantly motivating project-based activities [11] across both the K-12 STEM education system and the higher education (undergraduate/graduate) engineering degree programs can (a) advance the understanding of basic and advanced STEM concepts (b) improve the retention of STEM concepts learned in the classroom (c) gain the preparation necessary to make the students effective and competitive in their pursuit of STEM careers or professions.

Section 2: STEM Project Activities

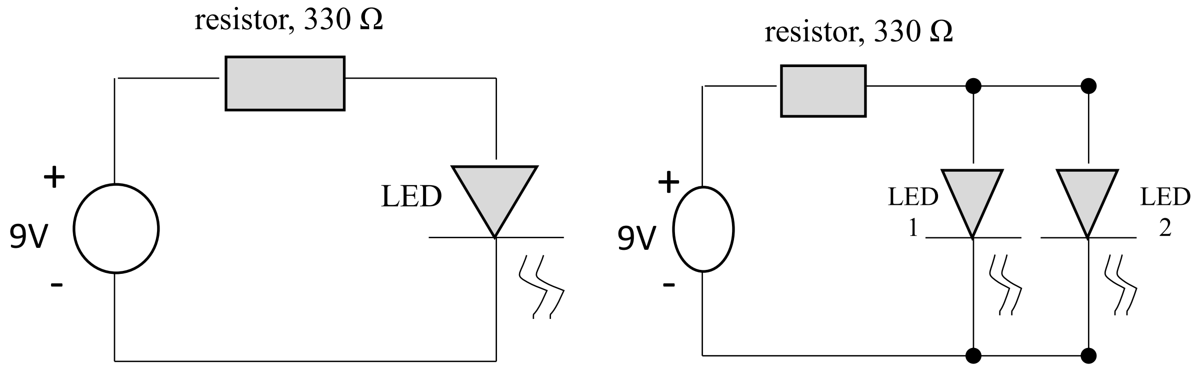
This paper discusses the STEM projects related to electrical and computer engineering which were delivered through (a) STEM day events at the schools (b) workshops with educators, and (c) laboratory exercises for the first-year engineering students. The STEM project for fourth grade at school A (4 A), seventh grade at school B (7B), eighth grade at schools B and C (8B and 8C) comprised the assembly and test of the series and parallel (shunt) electric circuit with resistive elements and light-emitting diodes (LEDs). The STEM project for the students in the sixth, seventh, and eighth grades at school D (6D, 7D, 8D) was based on Arduino-based LED electric circuits. The STEM project for the ninth grade (high school, 9E) comprised the electronic circuit for traffic signal control. The workshop for the STEM educators (school F) comprised structured exercises in electronics. The laboratory exercises for the first-year undergraduate (UG) engineering students consisted of the electric circuit for (i) timer control, and (ii) logic gates. Table I displays the number of sessions, the duration per session, and the total number of participants.

Table I: STEM Project – Session Information

STEM Project	Grade (School Label)	Duration/session (minutes)	Total # of attendees
Electric LED circuit	4(A)	55	65
	7(B)	75	55
	8(B)	75	63
	8(C)	40	112
Arduino with electric LED circuit	6(D), 7(D), 8(D)	180	60
Electric circuit - traffic signal control	9(E)	1	56
Electronic circuits	Educators (F)	120	4
Electric circuit - timer, logic gates	Engineering students (UG)	55	65

Elementary school

The fourth grade students at this school participated in the assembly of two simple electric circuits – series and parallel, with a DC power source, a resistor, and light emitting diodes (LEDs) as shown in Figure 1(a) and Figure 1(b) respectively.



(a) (b)

Figure 1: (a) Series circuit (b) Parallel circuit

The components required for the assembly and testing of each circuit were provided to each team of two students. The duration of each session was fifty-five minutes. The instruction phase, as shown in Figure 2, comprised an introduction to the components required for the assembly process as well as an explanation of the step-by-step procedure to perform the assembly and testing. Following the introduction, the students engaged in the assembly and testing process as captured in Figure 3.

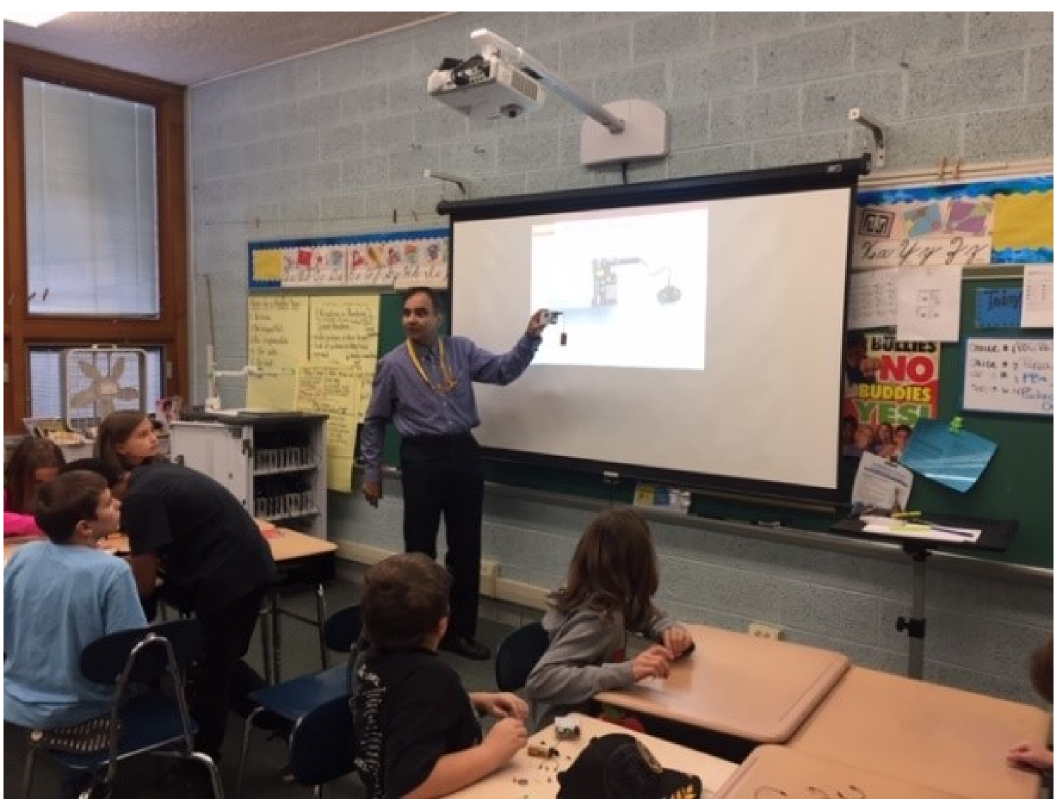


Figure 2: Instruction phase - Elementary school

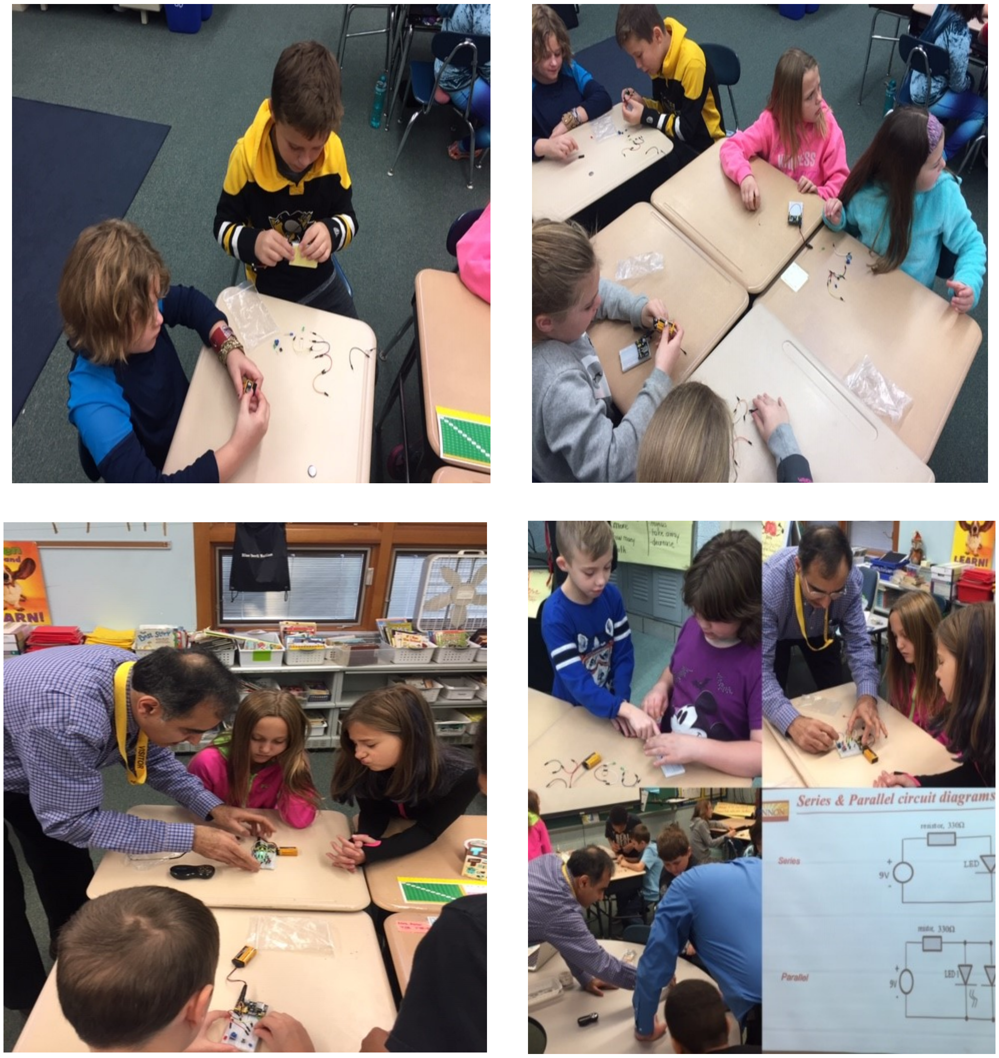


Figure 3: Project assembly and test phase – Elementary school

Middle School – electric circuits
The eighth grade students participated in the assembly of the same two circuits as above. However, these students had to include a potentiometer and a push-button switch to control the operation of each circuit. The duration of each session was forty minutes. The sessions are shorter compared to those for the students in the elementary school owing to the enhanced STEM preparation of the eighth graders over the fourth graders.

Figure 4 shows the instruction phase of the STEM activities. During this instruction phase, the step-wise assembly process was demonstrated to the entire group using the camera of an IPad mounted on a stand as seen in the Figure. Most of the students assembled the circuit concurrently. Following the introduction, the students, working in pairs, engaged in the assembly and testing process as captured in Figure 5.

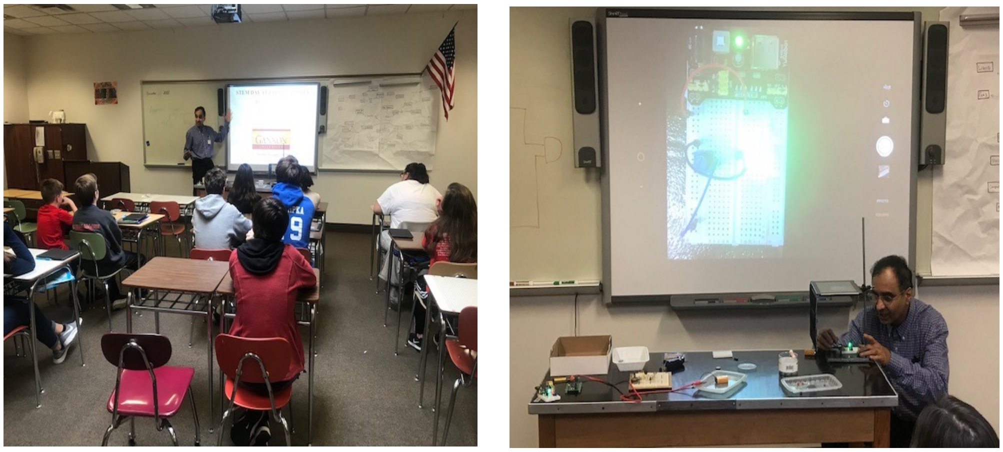


Figure 4: Instruction phase –Middle school

Figure 5: Project assembly and test phase – Middle school

Middle school – Arduino-based electric circuit

The sixth, seventh, and eighth grade students (total count: 30) worked with the Arduino Uno kit (includes the protoboard) as shown in Figure 6. The Arduino comprises a microprocessor with built-in serial debugging, USB programming, and protoboard-based circuit assembly integrated into one device.

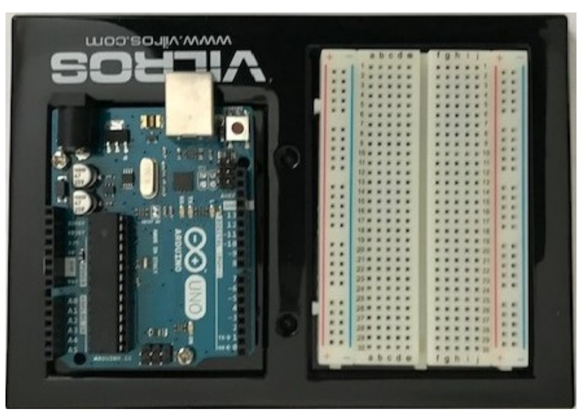


Figure 6: Arduino Uno kit with protoboard

The duration of the session was three hours and the students simulated, assembled and programmed basic and advanced electrical circuits. In order to enhance the overall STEM experience, the electrical circuits simulated and assembled by the students as part of each project are arranged to be completed successively in a pre-specified order. This enables the students to relate the content of each project to their learning outcomes from the preceding projects. The list of projects related to circuits comprising a light emitting diode (LED) are arranged as follows:

1. Test the operation of the LED
2. Blink the LED at a chosen rate
3. Blink arrangements of two LEDs at specified rates
4. Blink a sequence of LEDs in a specific order
5. Adjust the rate of the blink sequence of LEDs using a potentiometer

The STEM project activities comprised the following aspects.

(a) Simulate the electrical circuit using Tinkercad (as shown in Figure 7)
(b) Assemble the circuit on the protoboard of the Arduino kit
(c) Program the Arduino to control the operation of the assembled circuit
(d) Modify the program to meet revised project specifications
(e) Answer specific questions and challenges related to the project activities

Figure 7 shows the circuit simulated and assembled by the students as part of project 4.

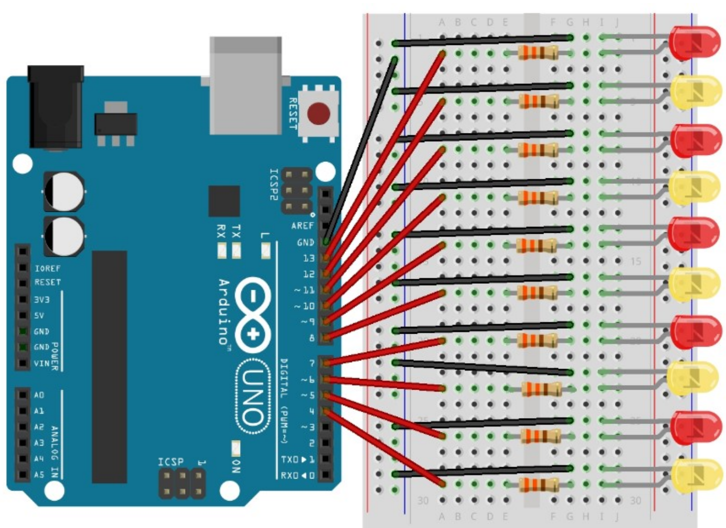


Figure 7: Multiple blinking LEDs in sequence

The circuit uses the program (shown in Figure 8) to operate the LEDs to blink (turn on and turn off) in a pre-specified sequence.

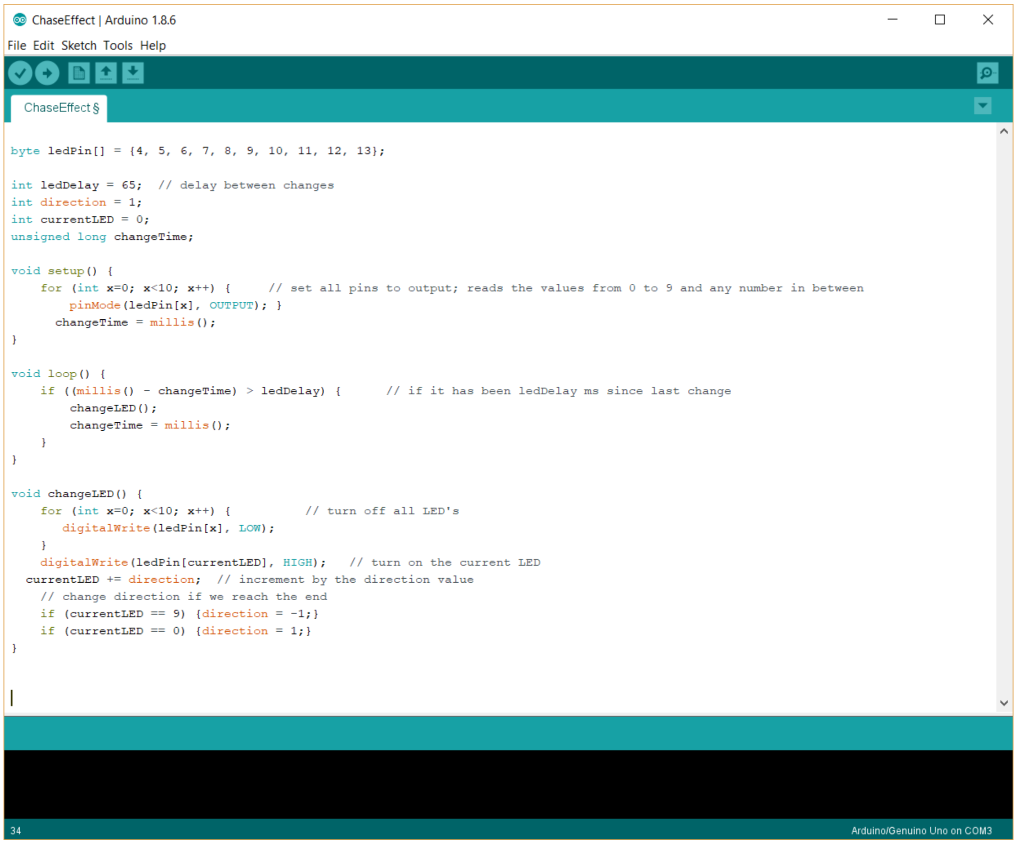


Figure 8: Program to blink the LEDs in a sequence

Figure 9 illustrates the environment for the project activities.

Figure 9: STEM project environment

Figure 10 provides examples of the circuit assembly and testing performed by the students.

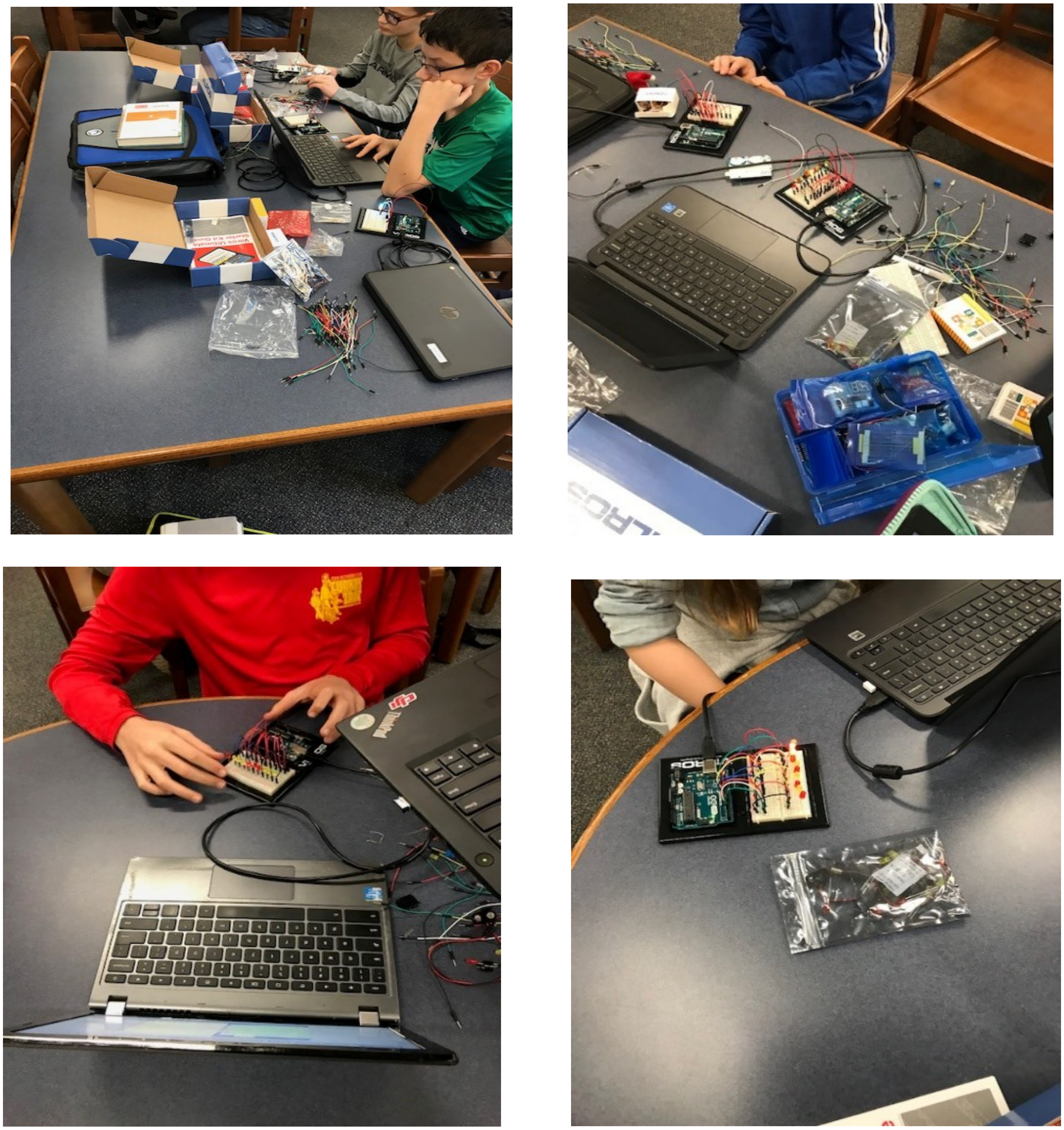


Figure 10: Examples of the assembly and testing phase of the project

The exercises with Arduino-based circuit operation successfully integrate the programming or software component with the hardware equipment. Specifically, the understanding of input control parameters and output display variables, and the distinction between continuous (analog), sampled and quantized (digital) signals is introduced.

High school
The students in the ninth grade at the school (9E) assembled and tested the circuit for traffic signal control. There were four sessions each with about 15 students in each session. The duration of each session was fifty minutes. Due to the short duration of each session, the STEM experience was limited to assembly and validation. The circuit components required are shown in Figure 11.

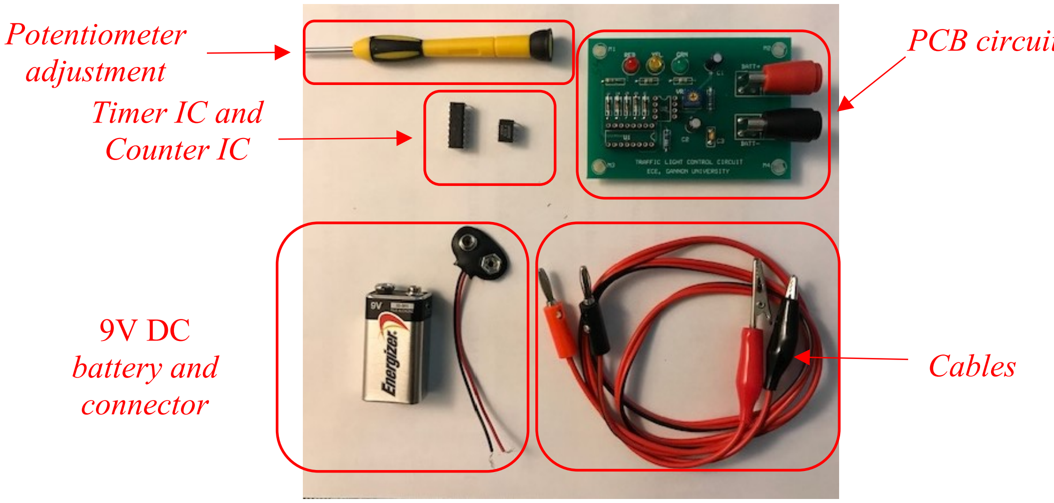
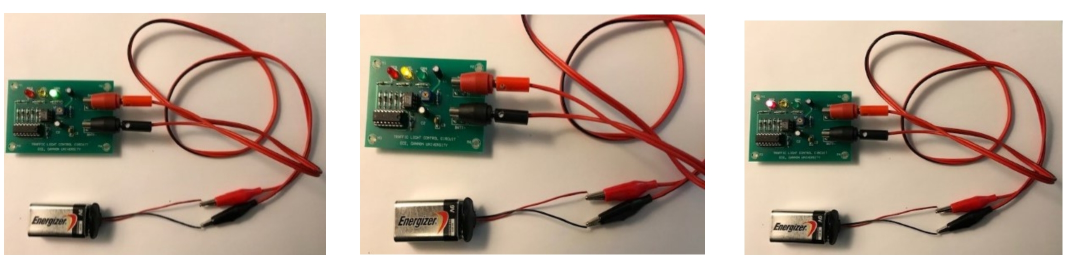


Figure 11: Components of the traffic signal circuit

During the instruction phase, the students were introduced to each component and its purpose in the process of assembly of the circuit. The steps to assemble and test the circuit were outlined as follows:

- Place the 555 timer in the circuit.
- Place the 4017 counter in the circuit.
- Connect the DC battery to the PCB
- Adjust the potentiometer and observe the LEDs.

The outcomes are illustrated in Figure 12.



(a) (b) (c)

Figure 12: (a) Green LED on (b) Yellow LED on (c) Red LED on

The survey administered to each grade of students is discussed in Section 4.

STEM Educators

Table II lists the sequence and the duration of each ECE-STEM project activity conducted at the ECE-STEM workshop for educators. The total duration of the workshop was two hours (120 minutes).

Table II: Workshop schedule

Category	Maximum Duration	Outline
Introduction & Overview	3 minutes	Schedule of topics & activities
Team formation	2 minutes	Two participants per team
Concepts: Circuit theory	5 minutes	Basics – components, units
Project #1: **Series & parallel circuits**	15 minutes	**Lamp and fan configurations**
Concepts: Circuit theory	5 minutes	Current and voltage laws
Project #2: Timer & relay circuit	15 minutes	**Transistor-relay LED control**
Concepts: Digital Logic	5 minutes	Boolean operations
Project #3: Logic gates with circuits	15 minutes	**Truth tables for NOT, OR, AND**
Concepts: Transistors – PNP, NPN	5 minutes	I-V relationship and operation
Project #4: Transistor circuit	20 minutes	**PNP configuration**
Concepts: Amplifiers	5 minutes	Voltage, current, power
Project #5: Amplifier circuit	20 minutes	**PNP & NPN transistors**
Wrap-up	5 minutes	**Discussion**

Sample overview and project activities

Following the introduction of basic circuit concepts through the variables, their units, and fundamental laws (Kirchhoff's Voltage and Current), the first project illustrated the configuration of the two basic electrical circuit configurations – series and parallel. Figure 13 shows the set-up of a lamp and a fan in series.

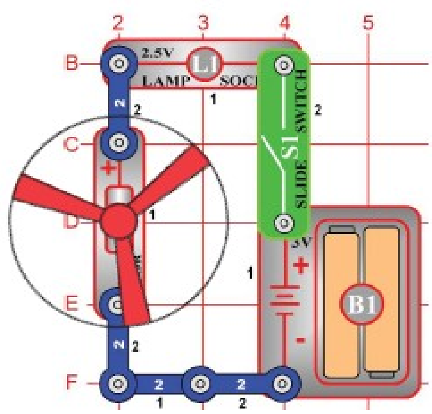


Figure 13: Project Activity #1(a) - Series circuit

The participants assembled the circuit shown in Figure 13. They were instructed not to touch the fan or motor during operation. Safety concerns form an integral part of electronic design and test, and were enforced throughout this workshop. Upon placement of the fan blade on the motor (M1), and closure of the slide switch (S1), the fan spins and the lamp (L1) turns on. The light helps protect the motor from getting the full voltage when the slide switch is closed. A part of the voltage from the battery source drops across the lamp and the rest drops across the motor. The participants remove the fan and notice how the lamp gets dimmer when the motor does not have to spin the fan blade.

The parallel circuit using the lamp and fan is shown in Figure 14. In this connection, the lamp does not change the current to the motor (M1). The motor starts a little faster than in the series circuit. The participants removed the fan and noticed how the lamp does not change in brightness as the motor picks up speed. The lamp has its own path to the battery (B1).

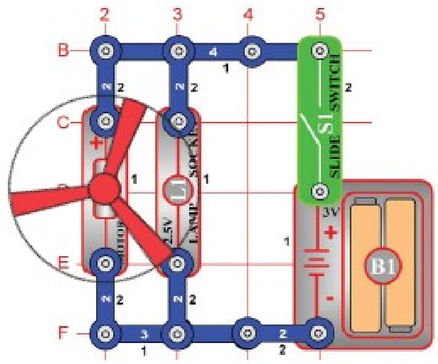


Figure 14: Project Activity #1(b) - Parallel circuit

Project #2 engaged the participants in the assembly of a timer circuit to control the operation of a lamp. Figure 15 illustrates the set-up of the circuit. In this circuit, switch S1 is the main power source, allowing the current to flow from the batteries to the circuit. When the switch S2 is pressed, the capacitor C5 charges, and this brings power to the base of the transistor Q2. The transistor then allows current flow through the collector and emitter activating the relay S3, switching on the lamp L2. After a set time, the capacitor C5 becomes de-energized, and the current through the base of the transistor no longer flows, deactivating the transistor, switching off the relay, turning off the lamp.

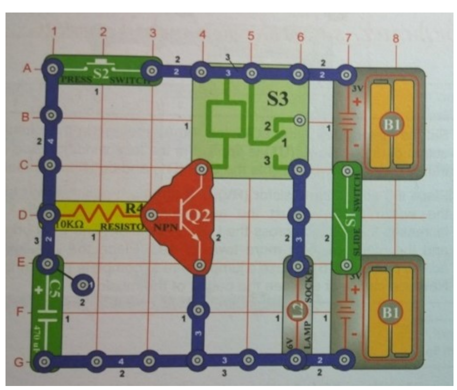


Figure 15: Project Activity #2 – Timer circuit

Project Exercise

First, change the value of the resistor R4 at the base for the same fixed value of the capacitor C5. Record the duration of time for which the light stays on for three choices of R4. Next, fix the value of R4 and vary the value of the capacitor C5. Record the duration of time for which the light stays on for three choices of C5. Tabulate the choices and the outcomes as shown in Table III.

Table III: Experimental data gathered

Value of resistor (Ω)	**Value of capacitor (F)**	**Duration, seconds (s)**

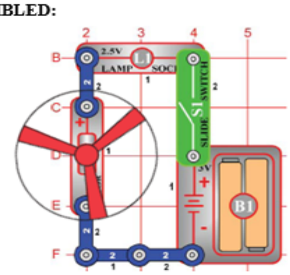
Project information

In order to facilitate individual and team participation, the attendees received the summary write-up for each project activity. Figure 16 shows a sample summary project activity write-up.

PROJECT ACTIVITY #1_A: SERIES CIRCUIT

OBJECTIVE: Use a series circuit to show how a lamp can indicate when a fan is running.

CIRCUIT TO BE ASSEMBLED:



STEPS IN THE ASSEMBLY:

1. Assemble the circuit shown above by placing all the parts with a black number 1 next to them on the base grid first.
2. Then, assemble parts marked with the black number 2.
3. Finally, place the fan blade on the motor (M1).

WARNING: There are moving parts in this circuit.
Do not touch the fan or motor during operation!!

OPERATION:

Close the slide switch (S1); notice that the fan will spin and the lamp (L1) should turn on.
The fan will take a while to start turning due to inertia.
The light helps protect the motor from getting the full voltage when the slide switch is closed.
Part of the voltage goes across the lamp and the rest goes across the motor.

TEST & VALIDATION:

1. Remove the fan and notice the effect on the lamp.
2. Record the evidence.

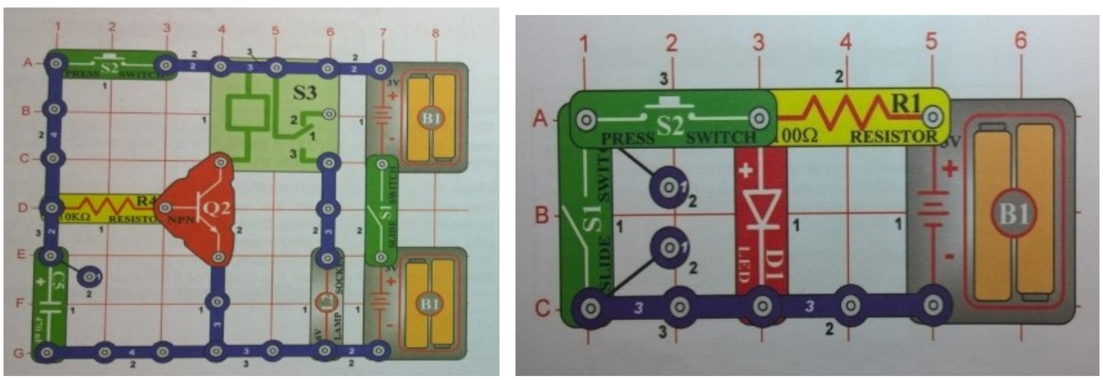
Figure 16: Sample summary project activity write-up

First-year undergraduate engineering students

Clearly, problem-based [10]–[12], project-based [13] instructional pedagogy together with self-directed learning [14], [15] train the first-year engineering students to (a) better understand and perform engineering laboratory exercises (b) cultivate skills related to experimental observation and evidence collection (c) gain useful STEM experiences for future courses and engineering professions. For instance, the ECE laboratory session to configure and test the operation of electric circuits such as the timer and logic gates has the following specific objectives.

- Build the timer circuit using a transistor and a relay
- Assemble logic gates using switches and light-emitting diodes (LEDs)
- Test the operation of the timer circuit and the logic gates

The timer circuit and the logic circuits are assembled with electronic kits which contain electrical components placed on circuit assembly boards and connected using snap connectors. Figure 17(a) displays a timer circuit. Figure 17(b) illustrates the NAND logic gate implemented using circuit components.



(a) (b)

Figure 17: (a) Timer circuit (b) Logic circuit

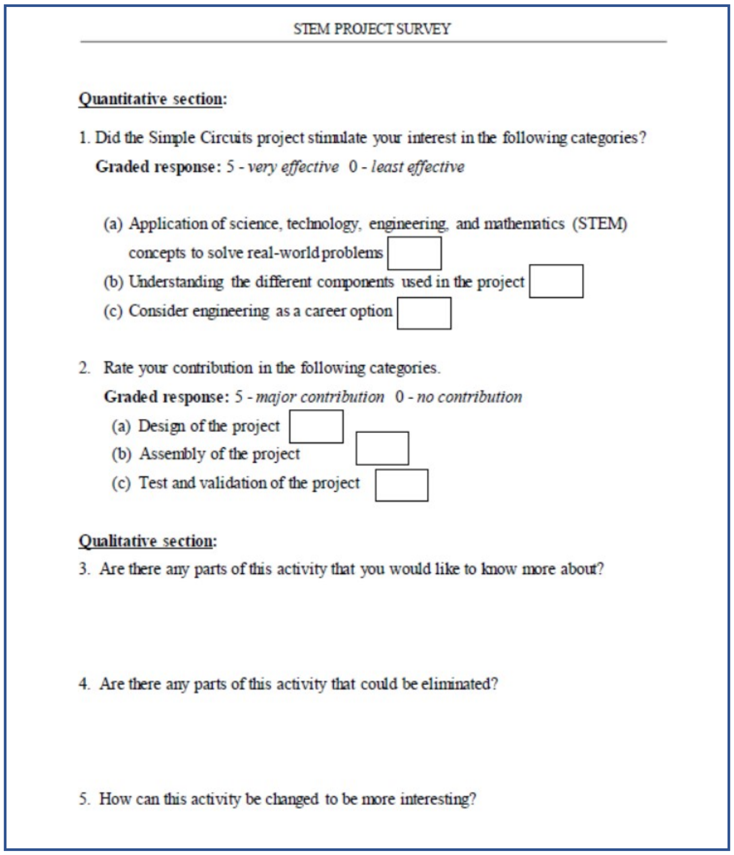
First, the students engage in the steps to assemble the circuit shown in Figure 17(a). To stimulate student recognition of engineering design specifications and parameter selections, the laboratory exercises related to control of the timer circuit and Boolean operations with logic circuits. Students collect evidence of timer control by choosing the resistors and capacitors from the kit. The evidence is documented as previously displayed in Table III. The students assemble the circuits to implement the NOT, AND, NAND, OR, and NOR logic gates. The operation of each gate is documented as shown in Table IV.

Table IV: Truth table for logic circuit

Position of the switch S1 (ON/OFF)	Position of the switch S2 (ON/OFF)	LED LIGHT (ON/OFF)

Section 3: Learning Outcomes Assessment

Figure 18 displays the survey administered following the STEM project activities. The survey comprised two sections (a) quantitative (b) qualitative. The quantitative section required the assignment of a score (integer between 0 and 5) to specific questions in the following two categories (a) stimulation (b) contribution. The survey was not completed by the attendees in 6(D), 7(D), 8(D), F, and UG due to time constraints.


STEM PROJECT SURVEY

Quantitative section:

1. Did the Simple Circuits project stimulate your interest in the following categories?
   Graded response: 5 - *very effective* 0 - *least effective*

   (a) Application of science, technology, engineering, and mathematics (STEM) concepts to solve real-world problems
   (b) Understanding the different components used in the project
   (c) Consider engineering as a career option

2. Rate your contribution in the following categories.
   Graded response: 5 - *major contribution* 0 - *no contribution*
   (a) Design of the project
   (b) Assembly of the project
   (c) Test and validation of the project

Qualitative section:

3. Are there any parts of this activity that you would like to know more about?

4. Are there any parts of this activity that could be eliminated?

5. How can this activity be changed to be more interesting?

Figure 18: Survey template

Quantitative section

Table V lists the average and deviation of the scores for the two categories. Figure 19 displays the average and deviation of the scores in the two categories.

Table V: Statistics of survey data – quantitative section

Grade # (School)	**Total # surveyed**	**Stimulation**			**Contribution**		
		Application of STEM	**Understand project components**	**Engineering as a career?**	**Design**	**Assembly**	**Test & Validate**
		Avg., Dev.	**Avg., Dev.**	**Avg., Dev.**	**Avg.,Dev.**	**Avg., Dev.**	**Avg., Dev**
4(A)	65	4.1, 1.1	3.6, 1.3	2.6, 1.9	4.0, 1.2	3.9, 1.1	3.6, 1.3
7(B)	55	3.3, 1.5	3.1, 1.6	2.0, 1.9	3.5, 1.4	3.3, 1.6	3.6, 1.5
8(B)	63	4.0, 1.1	3.6, 1.4	3.0, 1.6	3.8, 1.3	3.8, 1.3	3.9, 1.4
8(C)	112	2.9, 1.3	2.6, 1.4	2.0, 1.6	3.3, 1.2	3.5, 1.3	3.4, 1.3
9(E)	56	3.7, 1.3	3.3, 1.5	2.8, 1.6	3.8, 1.2	4.0, 1.0	4.1, 1.1

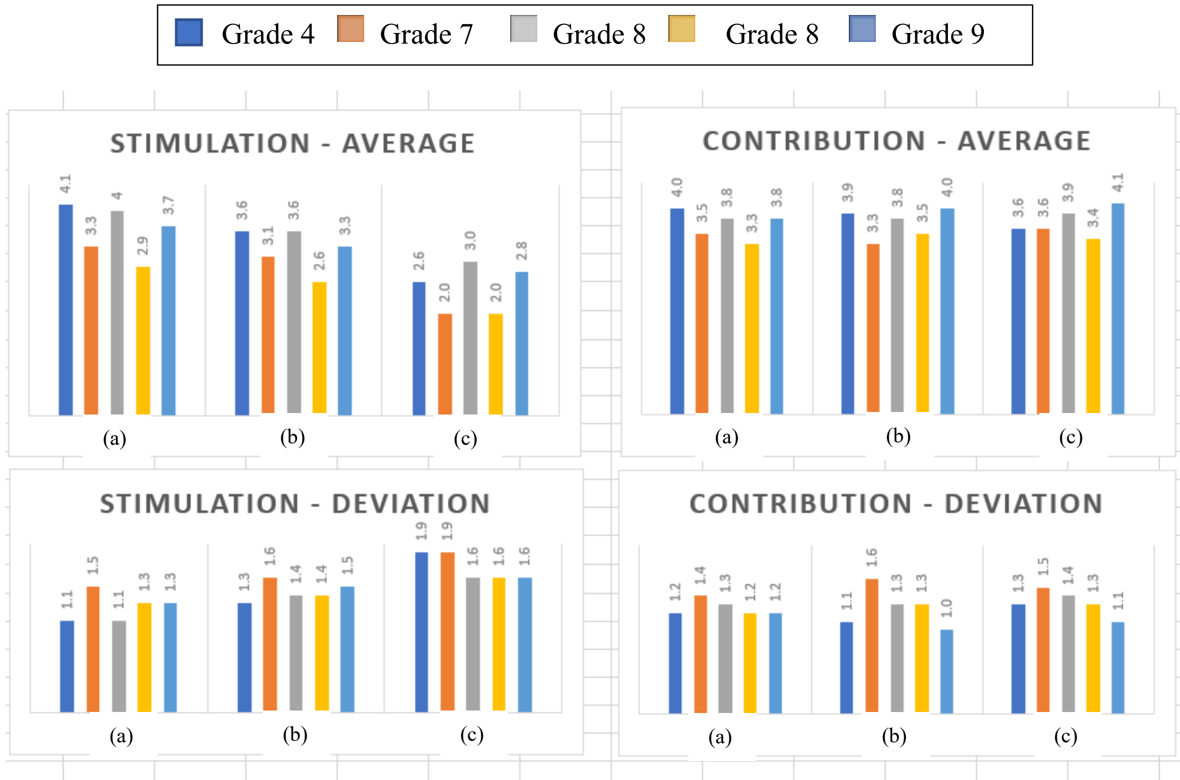


Figure 19: Average and deviation in the two categories

Stimulation

The response in the subcategory of (a) the application of STEM and (b) the understanding of the project components attained the combined average of 3.6 and 3.24 respectively. This indicates that the students recognized the electric circuit as a STEM application with components whose action could be understood. The response to choice of engineering as a career option recorded scores less than 3.0 and with the combined average of 2.48. Clearly, the students in the grades considered (i.e. four to nine across four schools) are as yet unfamiliar with the aspects of STEM that help them consider engineering as a career option. The STEM curriculum should consider the inclusion of STEM projects that ignite the interest and sustain the pursuit of engineering disciplines.

The shorter session (forty minutes for 8C versus the fifty-five minutes for 4A and seventy-five minutes for 7B and 8B, as documented in Table I) did not facilitate the clear recognition of the application of STEM and the understanding of the project components. The primary reason for the shorter sessions was to accommodate the larger total number of students (112 versus 75 i.e. 1.5 times) in the six sessions (about twenty students per session) during the available four contact hours of the school day. Consequently, the scores of 2.9 and 2.6 are the lowest in these two subcategories, and below the combined average of 3.6 and 3.24 respectively.

Contribution

The students worked in pairs. In this category, the intent was to determine the extent of the contribution made by each student in the design, assembly, test and validation steps of the project activities. The combined average in each subcategory exceeds 3.68 thereby confirming that each student was actively engaged during the project activities. In addition, the percentage of the students engaged during the session with an average greater than 3.5 across the three categories (i.e. Assembly, Design, Test & Validate) was approximately 70% for grade four and grade nine, and approximately 60% for grade seven and grade eight.

Qualitative section

The qualitative section sought feedback to help identify the (a) inclusion of additional STEM content and/or activities (b) exclusion of STEM content and/or activities, and (c) revised/alternate project activities to enhance the STEM experiences.

Sample comments from qualitative section

Grade: Four

Are there any parts of this activity that you would like to know more about?

- *Circuits, circuit components, circuit boards*
- *Electrical engineering*

Are there any parts of this activity could be eliminated?

- *Shorten the lecture component to allow more time for the hands-on activities*

How can this activity be changed to be more interesting?

- *Include moving parts, like a fan*
- *Give more time to assemble and test i.e. increase the duration of the event*

Grade: Eight

Are there any parts of this activity that you would like to know more about?

- *How to build complex circuits*
- *Description of the circuit components*
- *Details about other applications of the circuit board and the components*

Are there any parts of this activity could be eliminated?

- *All aspects are important*
- *Use less slides and more hands-on demonstrations*

How can this activity be changed to be more interesting?

- *Increase the duration of the event – need more time to assemble and test*
- *Include challenge exercises*
- *Reward the team which is first to finish the design and test of each circuit*

Grade: Nine

Are there any parts of this activity that you would like to know more about?

- *Relation to STEM courses*
- *The process of engineering design*
- *The background theory to understand the outcomes of the activity*

Are there any parts of this activity could be eliminated?

- *Use less slides and more hands-on demonstrations*

How can this activity be changed to be more interesting?

- *Increase the duration of the event*
- *Include video-based step-by-step instructions*
- *Add more hands-on activities*

STEM educators

The educators expressed the need for additional workshop sessions in order to determine the approach and effectiveness of the electronic circuit assembly and testing experiences of the projects for inclusion in the pK-12 classrooms and laboratories as part of the pK-12 STEM curriculum. In addition, the following comments are noted.

- *Increase the duration of each project*
- *Include analytic discussion at both the component and the system level*
- *Organize additional workshop sessions to reinforce the link between theory and practice*

Section 4: What's Next?

The goals in the future include (a) target each grade with integrated projects in electric circuits, electronics and microcontroller programming (such as is offered by the Arduino boards) (b) conduct this activity more often (e.g. once each month) during the school year (c) follow up with summer camps (e.g. three-day, week-long) on more advanced projects (d) include other engineering disciplines (e.g. mechanical, chemical and, environmental) in the outreach for inclusion of projects with multi-disciplinary aspects. The event cannot be conducted in isolation and with only a short exposure (less than one hour) to engineering laboratory activities but must include progress across projects at different scales of complexity. This will require additional time and commitment of resources to be effective.

Based on the responses to the survey questions, the students were actively engaged in learning how to assemble the electric circuit from the components. Their creativity was also explored with suggestions of additional project activities to include sound and motion control. The elementary school students (grade four) were at ease with the components and recognized the role of each component. The middle school students (grade seven to grade nine) were more challenged by the programming exercises which are part of the Arduino-based circuit control.

The students recorded low scores in choice of engineering as a career. This can be addressed in the future by either increasing the duration of each session or setting aside a separate session to overview and explain the potential for career and professional development possible in the different engineering disciplines.

Section 5: Conclusions

The STEM projects identified and implemented in this paper target specific STEM constituents and represent part of the broader interaction across educational communities to exploit the symbiotic and synergistic nature of these communities. The project activities range from basic to advanced exercises in electronic circuits, as well as integrate control and display of the circuits through structured command-based instructions in a software programming environment.

The samples of the qualitative responses documented in this paper represent the common theme of the feedback from one or more students. Some of the students recognized that the project activities formed not just part of the reinforcement of the classroom learning of STEM principles but also had some impact beyond the classroom on engineering design issues and constraints. Clearly, one of the aspects that should be emphasized at similar outreach events conducted by other institutions is maintenance of the close relation of engineering and technology to provide solutions to real-world problems. Projects which reveal such relationships should be identified and used in the STEM outreach events with the students and school educators.

In addition to the survey, the office of admissions at the institute of higher education record and track the students who participate in the event. This is easily accomplished when the event is held in the laboratories of the institutions of higher education. However, to be effective when schools are visited, one or more staff members of the admissions office would coordinate with the school being visited to maintain records of the participants and their progress toward graduation and beyond. Follow-up communications with information of appropriate incentives are effective means to attract the students to engineering degree programs which lead to advanced degrees and engineering careers or engineering-related professions.

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