MAKER: Shedding Light on Product Development in About an Hour

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Abstract

An active-learning experience has been designed to introduce grades 5-12 STEM students to product development. In a one-hour program, students are guided through the product development cycle as they construct a simple LED flashlight. This multidisciplinary project involves both electrical and mechanical elements plus a discussion of engineering design, manufacturing, and customer needs, which drive product development. This paper outlines the construction of the flashlight along with a method of instruction. It also includes a short discussion of assessment through student surveys.

Introduction

Active learning with tangible examples has been shown to improve retention while increasing satisfaction with the learning experience[1, 3]. In this project, a simple LED flashlight has been developed to provide grades 5-12 students with a high impact active learning experience centered on the role of engineering technology in product development. The simplicity of the flashlight has allowed for a multi-disciplinary approach to this process while staying within a one hour time frame. Students are exposed to electrical components, circuit design, mechanical design, manufacturing considerations, and the role of customers in product development.

Throughout the experience, a multidisciplinary approach is used to guide students through the assembly process. Electronic components are soldered to a prefabricated printed circuit board (PCB). Electronic design of the device includes discussion of component selection including the energy source, light source, switch, and resistor, plus a development of the prototype through simulation. Design of the mechanical housing allows for discussion of requirements that arise from design for manufacturability (DFM), design for assembly (DFA), serviceability, usability, and industrial design. Assembly also includes a snap-fit case that can be created with a 3D printer during the project.

The students are fully engaged as learners, makers, and customers as they each construct a flashlight. Student surveys following the exercise indicate a high level of satisfaction with the concepts and product. Students walk away with a self-made product and more importantly, a lasting impression of the accessibility of product development and engineering.

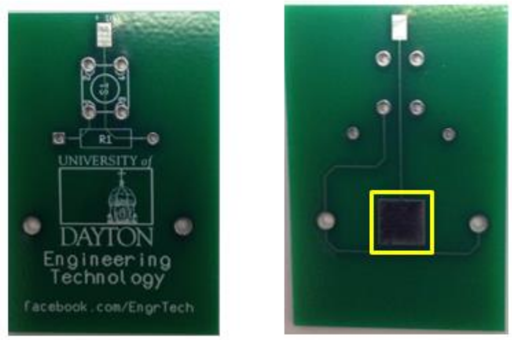
Construction

The components of each flashlight are pre-packaged into a kit for each student prior to each outreach workshop. The bill of material for the flashlight kit is included in Table 1. A one page handout (Item 9) with an overview of the circuit design, assembly, and function is provided with the kit. This handout is included in the Appendix. The circuit components (Items 2-6) are all standard catalog items. The printed circuit board (Item 1) is a custom board that has been developed by University of Dayton Engineering Technology faculty specifically for this outreach project. While the custom designed board may limit the ability to easily replicate the project, this component was refined to better represent a finished product and ultimately generate a more impactful student experience. The housings (Items 8 & 9) are custom 3D printed components which were also developed by University of Dayton Engineering Technology faculty to demonstrate various mechanical and manufacturing design features. Using a MakerGear M2 3D printer[4], a single set of housings was printed out of ABS without support material in about 30 minutes with less than 50 cents in material cost. The MakerGear M2 printer is comparable to many other low end fused filament fabrication printers and sells for less than $2000. Parts were also quoted externally and could be ordered from consumer 3D printing sources such as Shapeways[5] for about $15 per set. The construction of the flashlight is detailed in the steps that follow.

Table 1. LED Flashlight Kit Bill of Material

Item	Part ID	Qty	Description	Supplier	Unit Cost	
					100 qty	1000 qty
1	PCB	1	Printed Circuit Board	Custom PCB (1.19 x 1.75 x .06 inches)	$1.25	$0.66
2	BT	1	Battery Holder	Digikey	$0.30	$0.24
3	R1	1	43 Ohm Resistor	Digikey	$0.03	$0.01
4	S1	1	SPST Pushbutton switch	Digikey	$0.09	$0.06
5	D1	1	Red Light Emitting Diode (LED)	Digikey	$0.13	$0.12
6	Bat	1	3 Volt Coin Cell Battery	Digikey (CR2032)	$0.23	$0.12
7	HSNGA	1	Housing Front	Custom 3D printed part	$0.25	$0.25
8	HSNGB	1	Housing Back	Custom 3D printed part	$0.25	$0.25
9	INSTR	1	Circuit Design handout	Appendix	-	-
				Total Cost:	$2.53	$1.71

Step 1. The large square pad on the Printed Circuit Board (PCB) must be tinned for the battery contact (Figure 1).



a. PCB Front   b. PCB Back

Figure 1. Printed Circuit Board Battery Pad

Step 2. The battery holder (BT) is installed on the bottom of the printed circuit board (PCB) with its open side towards the lower edge. Its two terminals are then soldered into place on the top side of the board (Figure 2).

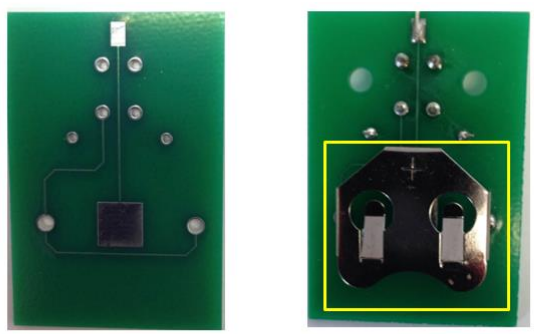


Figure 2. Battery Holder Assembly

Step 3. The resistor (R1) is installed in the terminals at R1 on the front side of the PCB. The leads should be bent outwards to secure the component in place. The leads can be soldered to the PCB terminals on the front side of the board. After the solder cools, the leads can be trimmed. (Figure 3)

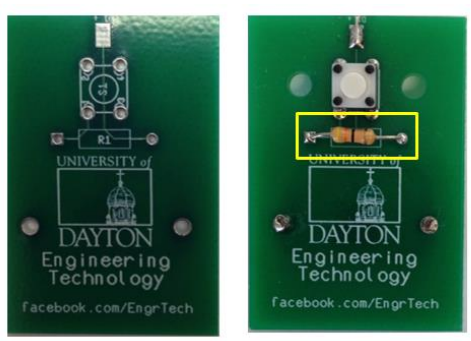


Figure 3. Resistor Assembly

Step 4. The pushbutton switch (S1) can be installed in the four terminals labeled R1 on the front side of the PCB. It should be pressed firmly until it snaps into place and is fully seated against the PCB. The four leads can then be soldered on the back side of the PCB. (Figure 4)

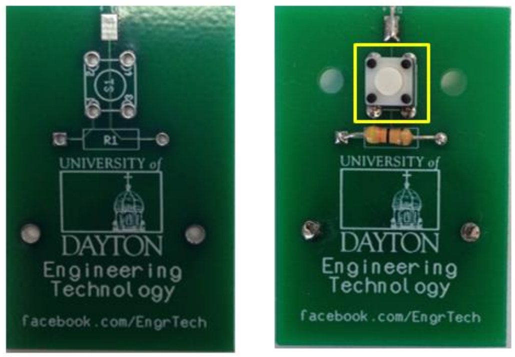


Figure 4. Switch Assembly

Step 5. The leads of the LED (D1) must be trimmed up to the joint (approximately 3/16 inches in length). The leads can be squeezed partially together so that it grips the board as it is assembled into place. It should be pushed up against the front edge of the PCB with the leads centered on the solder pads. It is critical that the flat side of the LED is towards the back side of the board since diodes are polarized components. (Figure 5)

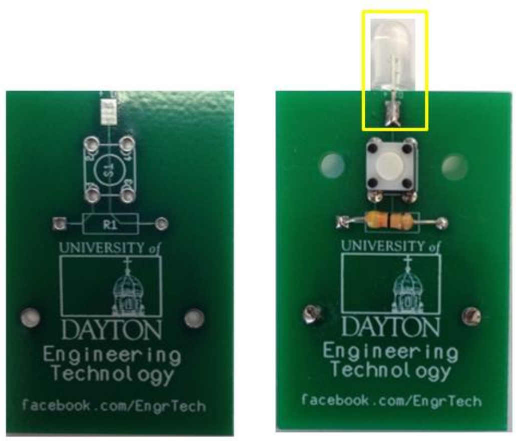


Figure 5. LED Assembly

Step 6. Insert cell battery into battery holder and test the circuit by pressing the pushbutton switch.

Step 7. Install the case. (Figure 6)

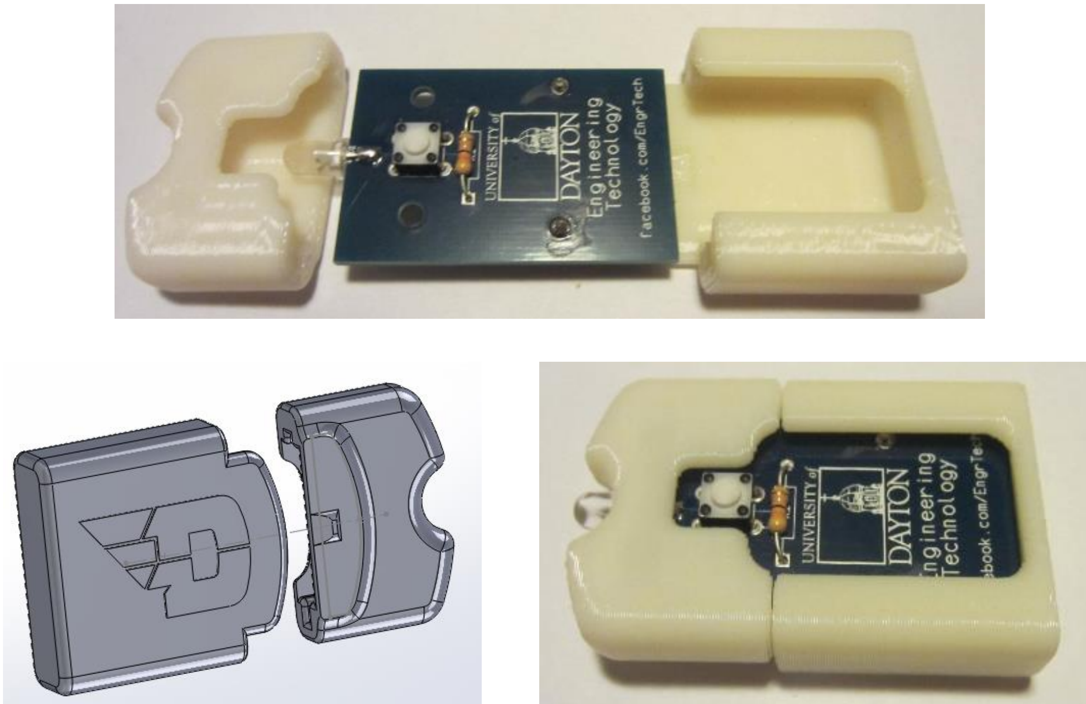


Figure 6. Case Assembly

Method of Instruction

As students are guided through the construction of the flashlight, they are also instructed on the theory of operation and practical design considerations pertinent to each step. A presentation has been developed as an instructional guide for this workshop. Before beginning the presentation, students are typically asked if they are aware of the differences between Engineering and Engineering Technology majors. This allows for introduction of the practical aspects of Engineering Technology curriculum with focus on application to commercial and industrial products.

Instruction begins with a quick overview of a flashlight circuit (Figure 7). This provides a glimpse of the finished product and a framework for the detailed steps to follow. Since most high school students already understand the basics of current flow in a flashlight circuit, this immediately builds confidence and sets the tone that engineering is an accessible profession.

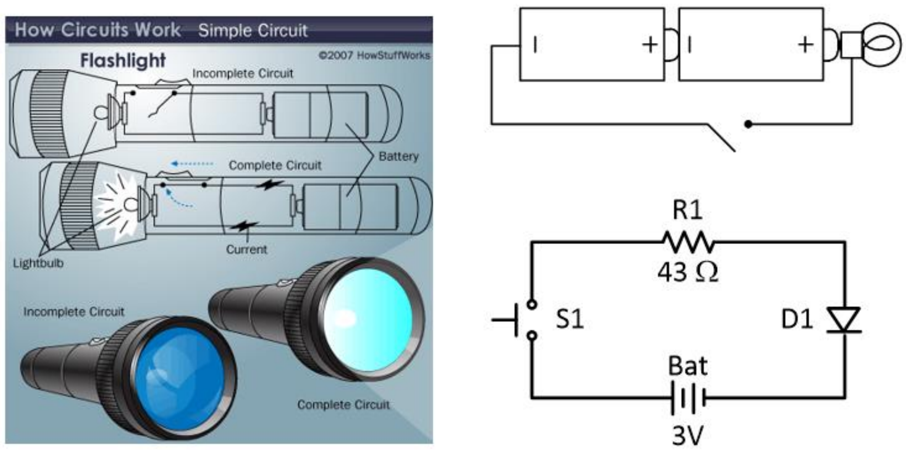
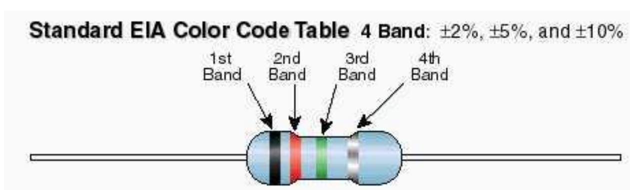


Figure 7. Overview of Flashlight Circuit

After a brief discussion of energy storage and battery selection, students are introduced to soldering with the tinning of the battery pad in step 1 of the construction. The target of such a large copper pad is perfect for those students who have never soldered before. They are instructed to heat the pad with the soldering iron and feed solder onto the pad for a good bond. This is also a great opportunity to discuss how soldering provides both an electrical connection and mechanical bond. Once the students have finished tinning the battery pad, they are able to practice their newly acquired soldering skills in step 2 with soldering the battery holder in place.

Next, there is a brief theoretical introduction of Ohm's Law and the role of resistors in circuits. Moving from theory to application, there is a short exercise performed using the EIA color code table to decode the value of the resistor used for the flashlight based on its color bands (Figure 8). Following this exercise, students once again get to practice their soldering skills with assembly of the resistor in step 3.



Color	1st Band (1st figure)	2nd Band (2nd figure)	3rd Band (multiplier)	4th Band (tolerance)
Black	0	0	10^0	
Brown	1	1	10^1	
Red	2	2	10^2	±2%
Orange	3	3	10^3	
Yellow	4	4	10^4	
Green	5	5	10^5	
Blue	6	6	10^6	
Violet	7	7	10^7	
Gray	8	8	10^8	
White	9	9	10^9	
Gold			10^{-1}	±5%
Silver			10^{-2}	±10%

Figure 8. Resistor Color Code Chart.

The switch is the next topic of discussion. Again there is a brief discussion of theory and the role of the switch in the circuit. This is quickly related to practice by presenting a slide illustrating a variety of different switch schematics right next to commercially available switches (Figure 9). Students are asked to identify the schematic for the pushbutton switch used for the flashlight prior to soldering it in place on the circuit board in step 4.

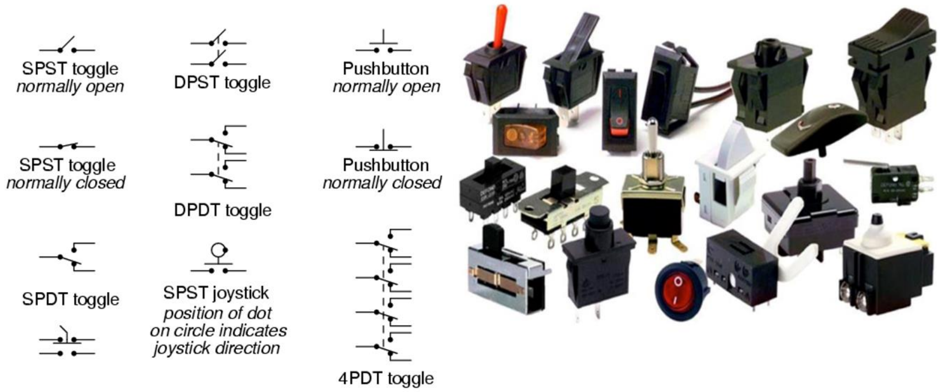


Figure 9. (A) Common Switch Schematics and (B) Commercially Available Switches

The LED is the final circuit board component. Once again, it is introduced with some basic theory including discussion of polarization, the concept of forward voltage, and energy released in the form of light. The forward voltage of just over 2 Volts for this LED is linked back to the previous circuit design work of selecting an appropriate resistor in series with the diode to achieve this value. From a practical standpoint, a slide with various LED's is presented and students are shown how to determine the positive lead (large flag, long lead) from the negative lead (no flag, short lead) (Figure 10). The discussion moves on to the application of energy efficient LED technology in devices ranging from cell phones and televisions to light bulbs and traffic lights, this topic typically generates some discussion. The LED leads are then clipped and soldered to the board per step 5.

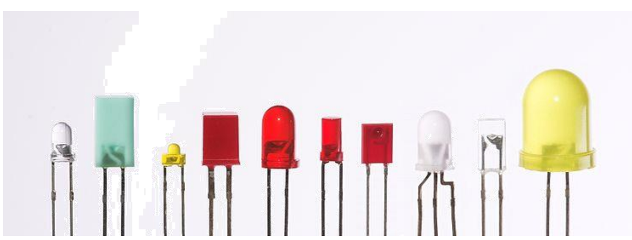


Figure 10. Various LEDs

With the circuit complete, the students are able to insert the battery and exercise the circuit they just created. Before the mechanical housing is even introduced, the students have typically pulled them out of their kits and snapped them over the PCB. At this time, the discussion is directed towards the product development aspects of the flashlight. Students are asked an open ended question about what features of a flashlight would be important to a customer. After a short discussion it becomes apparent that requirements can be wide ranging and are typically specific to a customer's application of the product. A slide with a variety of flashlights is presented to emphasize this point (Figure 11). The features that were designed into this flashlight are then introduced. These include a bright LED with long life, LED impact protection built into the housing, an ergonomic finger grip, a large window in a snap fit housing to expose the students' handiwork for sharing with others, and University Logos for personalization and marketing.

Figure 11. Customer Driven Flashlight Features.

The discussion is then directed back to the development of the mechanical housing. Nearly every student will have experienced a television remote with a broken battery cover snap fit. Raising this point will highlight the importance of robust mechanical design through analysis and testing even on something as low tech as the snap fit on this flashlight housing. The housing also allows for an introduction to mechanical design from napkin sketch to 3D printed prototype and beyond (Figure 12). It also allows for discussion of requirements that arise from design for manufacturability (DFM), design for assembly (DFA), serviceability, usability, and industrial design. While these housings were designed specifically to be printed on a consumer grade 3D printer, higher volume products would be designed with other processes in mind. If a 3D printer is available, a set of housings can even be printed within the time of the workshop for added impact to the experience.

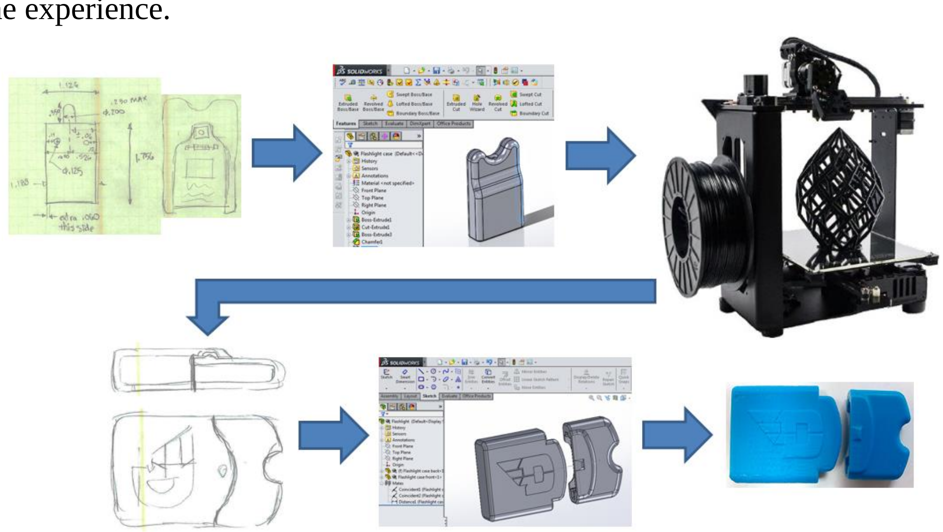


Figure 12. The Iterative Mechanical Design Process

Finally, as students clean up their work areas and gather their belongings, they are reminded that they are indeed the customers of this product experience and any feedback is welcomed. The students have been engaged as both maker and customer, and they walk away with an interesting flashlight and lasting impression of the accessibility of product development and engineering.

Conclusion

Student surveys are conducted each time the workshop is performed. This includes annual programs for a “Women in Engineering” outreach and also a more general “Explore Engineering” outreach. These results are summarized in Table 2. The majority of students rate their experience as excellent in nearly every session. The 3D printed housing was first introduced at the Fall 2015 Explore Engineering Event at which the workshop received 100% excellent ratings.

Table 2. Results of Student Surveys

Event	Rating Percentages			
	Excellent	Good	Fair	Poor
2012 Women in Engineering	74	22	4	0
2013 Women in Engineering	71	27	2	0
2012 Fall Explore Engineering	60	40	0	0
2013 Spring Explore Engineering	56	44	0	0
2013 Fall Explore Engineering	67	0	33	0
2014 Spring Explore Engineering	100	0	0	0
2015 Spring Explore Engineering	25	75	0	0
2015 Fall Explore Engineering	100	0	0	0

In addition to these ratings, the workshop receives many positive comments. A few of these comments are included below, again illustrating the positive impact of the workshop.

- “So much fun! I love how we make useful products. Professors provided great overview and were so great!!”
- “Very, very hands-on and had very obvious connections to respective engineering field. The professors were the best and explained everything. Their explanations of each part really left me with a deep understanding.”
- “So much fun! We learned so much about the technology part of engineering and even got to create our own circuits and flashlight case.”

While the workshop has been successful, it is always being refined and improved. This project has been used to introduce students to applied engineering careers for several years. It began as a project focused on electrical engineering technology and practical circuit design. The 3D printed housings were later added and refined to create a more multidisciplinary project. This has allowed the workshop to maintain hands-on circuit board development elements while also emphasizing the broader impact of engineers in product development.

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5. Shapeways. http://www.shapeways.com/. Last accessed January 16, 2016.

Appendix: Project Handout

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Practical Electronic Circuit Design

Assembly Instructions

1. Tin the large square pad for battery holder (BT).
2. Install the battery holder (BT) on the bottom of the printed circuit board (PCB) with its open side towards the lower edge. Solder the component in place.
3. Install the resistor (R1) in place on the PCB. Bend the leads slightly to secure the component in place, and solder. Trim the leads. See Figure 1.
4. Install the pushbutton switch (S1) by pressing it into the top side of the PCB until it snaps into place. Solder the component in place.
5. Clip the leads of the LED (D1) after the joint and slide onto top edge of board over top and bottom pads with flat side of LED down (this device is polarized). See Figure 2. Solder the component in place.
6. Insert cell battery into battery holder. Test the circuit by pressing the pushbutton switch.

How The Circuit Works

Analysis of this simple series circuit can be done using Ohms Law which states

$$V = I \times R$$

where V is voltage, I is current and R is resistance. The battery (Bat) provides 3V of potential energy to the circuit. Once the pushbutton switch (S1) is pressed, current is allowed to flow through the resistor (R1) and the light emitting diode (D1). The flow of current through the LED causes it to be forward biased, resulting in photons of light to be released. The resistor is used to regulate the amount of current flowing through the circuit, ensuring the LED is operating at the desired intensity. Releasing the pushbutton switch breaks the circuit, causing the current to stop flowing through the LED.

Parts List

PCB	Printed circuit board (PCB)	
BT	Battery holder	
R1	43 Ω resistor	YELLOW-ORANGE-BLACK
S1	SPST Pushbutton switch	
D1	Red Light Emitting Diode (LED)	
Bat	CR2032 3V coin battery	

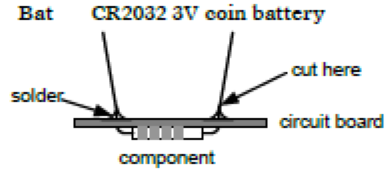

Figure 1. Soldering technique

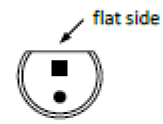

Figure 2. LED

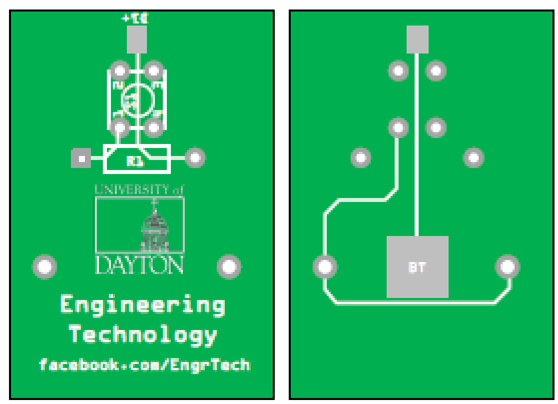

Figure 3. Circuit board layout

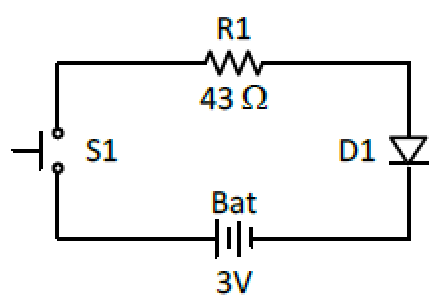

Figure 4. Schematic diagram

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