# How Many Students Does It Take Before *We* See the Light?

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Prior research suggests that students who cannot light a bulb given a single wire, a bulb, and a battery are not able to reason correctly regarding complete circuits. Our research shows that students believe that the wires from the filament are connected to the base of the bulb at the bottom. The percentage of students with this belief seems to be dependent on the level of the introductory physics course taken (conceptual, algebra, calculus). We have proposed three activities that appear to aid students in developing the correct model of how a light bulb is wired and a definition of complete circuit that classifies a short circuit as a complete circuit but one that is not advantageous.

Try giving one of your students a battery, a bulb, and some wires and ask him or her to make a bulb light. You will find that this simple task will cause many students great difficulty. James Evans[1] notes the low success rate of performing this task among high school seniors, university students, and university graduates. McDermott and Shaffer[2] suggest that students who have difficulty with the bulb-lighting task fail to understand and apply the concept of a complete circuit. Evans, however, asserts that "most of the students have no idea of the way the various wires inside a light bulb are connected. Lacking this understanding, how secure can they be in their understanding of 'circuit'?"[3] Yet, no research to date suggests how students think the wires inside a light bulb are connected.

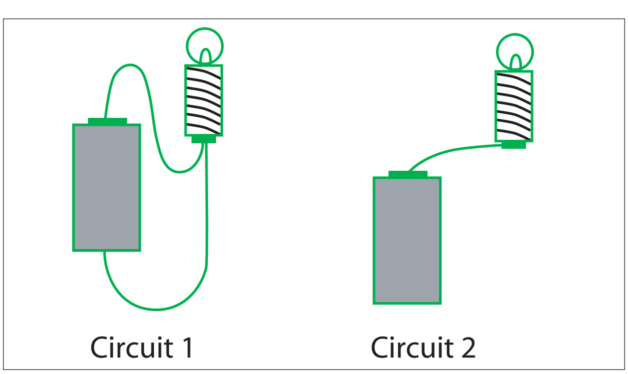


**Fig. 1. Typical drawings given by students while trying to make a light bulb light.**

Research[4] indicates that students have difficulty lighting a bulb given one wire, a battery, and a bulb. Does this result truly indicate that they do not understand the concept of a complete circuit as previous researchers have suggested? Or is it more that they do not know how a light bulb is wired internally? Furthermore, what do we, as physics instructors, mean by the term "complete circuit?" It is generally not a term that is explicitly defined in introductory textbooks. Students who were interviewed define it as "a complete path for _____ (energy, current, etc.) to move with no breaks." By this definition, a short circuit is also a complete circuit. We disagree with the inference of McDermott and Shaffer that suggests that a student who makes a drawing as shown in Fig. 1 (Circuit 1), or who cannot make a bulb light given a battery and one wire does not understand the concept of a complete circuit. We contend that the student does not understand the internal wiring of the light bulb and may have difficulty identifying a short circuit. In some respects the drawing itself is confirmation that the student understands a complete circuit; otherwise,


DOI: 10.1119/1.1696589

**Table I. Results from question asking where the wires connect to the "invisible" portion of a light bulb.**

| Class | Both wires to the bottom | Both wires to the side | One wire to the bottom, one wire to the side | Other |
|---|---|---|---|---|
| Calculus-based | 18% | 5% | 72% | 6% |
| Algebra-based | 58% | 9% | 25% | 8% |
| Conceptual-based | 70% | 0% | 30% | 0% |

the drawing would look like that in Fig. 1 (Circuit 2). There is a complete path for the charges to flow — it simply does not flow through the bulb. We as educators need to be more precise in our definition of a complete circuit. At present, its meaning is hidden from the students and not clearly defined in our textbooks. We suggest the following definition:

> A complete circuit is any complete path in which charges can move having no breaks or gaps. A short circuit is also a complete circuit; however, it is not an advantageous circuit as the element that is intended to receive charge does not because the charges are following the path of least resistance, and therefore, bypassing the element.

This paper will present the results of a one-question survey to ascertain students' ideas of the internal wiring of a light bulb. We have already suggested a useful definition of a complete circuit and will offer a set of promising activities to help students better understand how a light bulb works, strengthening their idea of a complete circuit and enabling them to determine where the contact points are on a light bulb and a socket.

## So How Do Students Think a Bulb Is Wired Inside?

In order to answer this question, a one-question survey was created asking students to draw the location of the wires connecting to the base of a light bulb (see Fig. 2). The survey was given to 124 first-semester introductory calculus-based engineering students, and 149 first-semester introductory algebra-based general physics (GP) students at Kansas State University (KSU) in spring 2003. The results from the survey and additional data from 10 interviews with introductory conceptual physics students are presented in Table I. One intriguing observation is that the results for the calculus-based and the algebra-based students are almost exactly reversed. There appears to be an effect from the level of the physics course taken. More research will need to be done to uncover precisely why this is so; however, this is not the focus of the present paper.

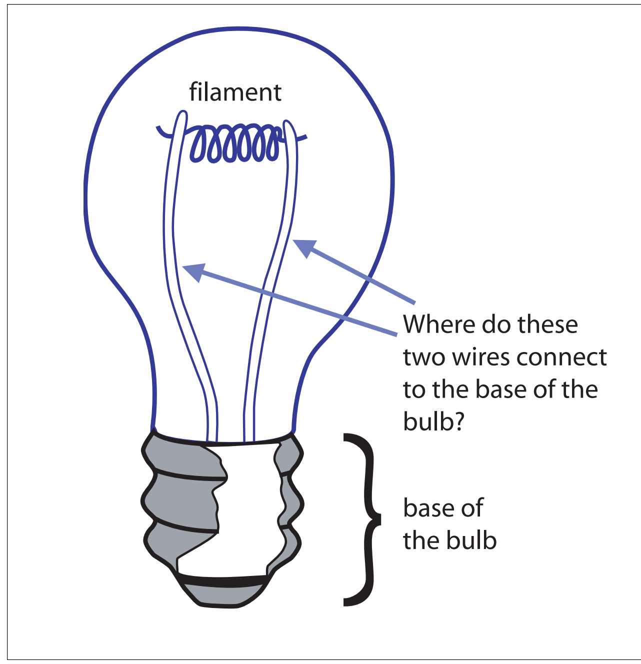


**Fig. 2. Diagram given to students to answer the question, "On the figure of the light bulb, draw in where you believe the two wires that come from the filament connect to the base of the bulb."**

## "Making Sense of Incandescence"

From Table I, it is clear that more than 50% of our general education physics students have an incorrect image of the internal wiring of a light bulb. So, how does an instructor help a student develop the correct view of the internal wiring of a light bulb? We would like to suggest the following three activities, which we have chosen to call "Making Sense of Incandescence."[5] These activities are not intended to replace traditional circuit activities, but to make them more effective by strengthening the students' understanding of a complete circuit and developing the correct view of how a light bulb is internally wired and how it op-

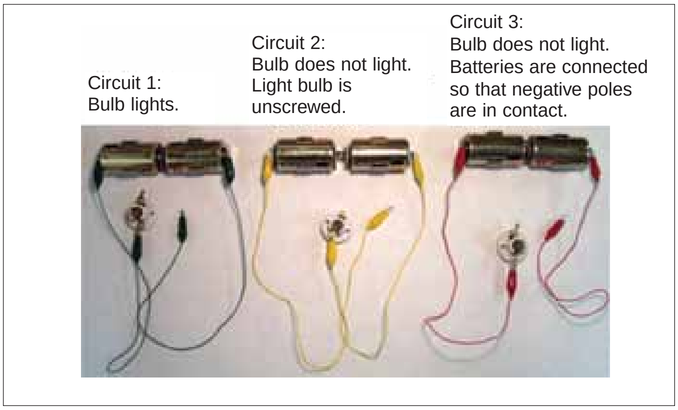


**Fig. 3. Circuits for Activity 2: That Glowing Feeling.**


**Fig. 4. Equipment used in Activity 3: Getting Connected.**

erates. These activities grew out of the interview protocol used with the conceptual physics students. They were initially developed for and pilot-tested with students at a local high school in Kansas, but have since been used with university-level conceptual physics and general physics students. "Making Sense of Incandescence" loosely follows the learning cycle,[6] which has three components: an exploration (Bright Ideas), a concept introduction (Activity 1: Getting Hot; Activity 2: That Glowing Feeling; and Activity 3: Getting Connected), and an application (Lighting Up the Night). The activities are done in stations. The activities will now be described in more detail.

The exploration activity, Bright Ideas, elicits the students' initial ideas about the concepts that are presented in the remainder of the activities and serves as a baseline to see what conceptual changes occur during the activities. Students are asked to describe how a light bulb works, how they believe the wires are connected to the base (given Fig. 2 on which to draw), to what other circuit element(s) the bulb is most similar (wire, battery, resistor, capacitor), what experiences led them to choose their answer, and to define in their own words what is meant by a complete circuit.

**Activity 1: Getting Hot** is intended to help students better understand how the light bulb functions via a comparison with another well-known device, the heating element from an electric stove. Students are led through a series of focused questions to determine how a light bulb filament and the heating element from an electric stove are similar and dissimilar to one another. Students also determine the number of connections each has, and whether or not the orientation of the connections to the battery is important.

**Activity 2: That Glowing Feeling** tests their idea of a complete circuit and confronts the idea that, although three circuits may physically appear to be identical, their actual operation may not. Students problem solve to find out why two out of three identical-looking circuits do not function. The circuits are shown in Fig. 3 as they first appear to the students. Circuit 1 in Fig. 3 will result in the bulb lighting after the final connection is made. In the other two circuits, the light bulb does not light after making the final connection. In Circuit 2 (Fig. 3), the bulb is not fully screwed into the socket creating a break in the circuit. In Circuit 3 (Fig. 3), the batteries have been hooked together so that the negative poles are in contact with each other. Prior to making the final connection, students are asked if the circuits are complete based on their definition from the Bright Ideas exploration activity. They make the final connection and are again asked if the circuits are complete. If they answer that the circuit is not complete, then the students are asked to problem solve as to why the bulb would not light, fix the problem, and explain how this situation initially resulted in an incomplete circuit.

**Activity 3: Getting Connected** directly confronts students' alternative image of how a light bulb is

**Fig. 5. Equipment given to students for the application activity, Lighting Up the Night. Students were not allowed to use the yellow body of the flashlight, although it was given for them to reference.**

internally wired. Its goal is to make a Christmas tree bulb light using a 6-V lantern battery connected to a large household socket (see Fig. 4). Students do this by first exploring how the socket works. Students record all their attempts to make the Christmas tree bulb light and note at what points on the socket they have tried. Near the end of this activity, they are given a battery, a wire, and a bulb and asked to make the bulb light given their new understanding of the internal wiring of a light bulb.

The application activity, Lighting Up the Night, provides students a chance to test their understanding of a complete circuit and their newfound knowledge of the internal wiring of a light bulb. Students are given a flashlight, two batteries, and some wires (see Fig. 5). They are asked to light the bulb without using the yellow casing. The casing is provided to the students for them to reference.

## Field Testing the Activities

The activities have been used with three different populations of students: high school physics ($N = 13$), and two introductory-level university groups — algebra-based general physics ($N = 29$), and conceptually-based physics ($N = 12$). Both of the university groups were enrolled in summer school. All students had already begun their study of electric circuits. The qualitative nature of the activities was unusual for all three groups. The high school students typically performed few hands-on laboratory experiments, but were shown many demonstrations in class. The most recent set of demonstrations dealt with electricity and was demonstrated in part via a Van de Graaff generator. Having seen what electricity could do via these demonstrations, the high school students were reluctant to initially touch and interact with the equipment. The university students were accustomed to quantitative laboratory activities that required numerous calculations and were more self-paced.

The students began by answering the questions in the Bright Ideas activity. We recommend having students independently answer the questions from Bright Ideas in the classroom so that their own ideas are elicited and not the ideas of someone else, or the textbook. For the field test with the high school and general physics group, each of the authors was at a station (what a luxury!) to help guide and focus the students' work, as well as to observe how the students interacted with the activities. Students were divided into three groups of two to four people. For the larger general physics class, we had 10 students per station subdivided into smaller groups of three to four. Sufficient equipment was available for each group. Groups rotated between the three stations. The order of rotation did not matter. After all three stations had been completed, we had a discussion that crystallized the main ideas from each of the activities. The main ideas were how a light bulb works, how it was connected within itself and to a socket, and what constituted a complete circuit. The final activity was Lighting Up the Night followed by a minute paper to reflect on what they had learned and pulled together from the activities. The minute paper also served as an evaluation of the activities. The high school students had 40 minutes to complete the activities while the university groups had an hour and 50 minutes. Thus, there were difficulties completing all of the activities with the high school students. In the future, we recommend two class periods for those with 40- to 50-minute periods.

When the high school students were asked how they liked the activities, most responded positively. The main complaint was lack of time to complete all the activities and to discuss the meaning of their results. One student remarked that there were not enough hands-on experiences in Activity 1: Getting Hot. Others did not see how Activity 1 was linked to the other two activities. We feel that this link, had time permitted, could have been established during

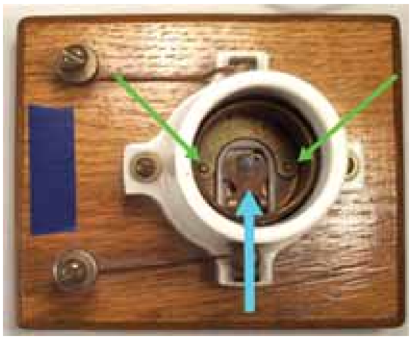

**Fig. 6. Socket similar to those used for Activity 3: Getting Connected. The green arrows indicate the locations of the point where the base is connected to the side. The large blue arrow indicates the tab on the base where many students tried to connect both wires from the Christmas tree light.**

the discussion phase. In Activity 2: That Glowing Feeling, some students in the high school and general physics groups believed that the light bulb was polarized so that a change in the wire connections would result in the bulb not lighting. We believe that this is an artifact of overemphasizing the direction of current flow during instruction. We have hence added to Activity 1 a section that deals with the issue of whether a bulb is polarized or not. In Activity 2: That Glowing Feeling, students were not accustomed to unscrewed light bulbs and had difficulty seeing how this would affect the lighting of the bulb.

The university-level students were split with their evaluation of the activities. Those who had an incorrect view of the internal wiring of a light bulb found the activities useful, often clearing up their confusion about how a light bulb functions and connects to a circuit. Those who had the correct view found the activities trivial. Both groups found parts of the activities to be repetitive. For this group of students, we recommend adapting the activities and incorporating all or parts of them into an existing activity dealing with light bulbs and simple circuits.

For most students Activity 3: Getting Connected was the most illuminating. It was during this activity that students' alternative image of the internal wiring of a light bulb was most strongly confronted. Many students began by trying to touch both leads from the Christmas tree bulb to the metal tab (indicated by the blue arrow in Fig. 6) of the socket. Students were visibly surprised when this did not work and proceeded to try other combinations. After several attempts, students found a combination that worked with little or no prompting. Students often found two screw (see green arrows in Fig. 6) connections on the bottom of the socket, which connected a metal strip on the base to the side of the socket, and would attempt to connect between them, which would result in the bulb lighting. They, however, did not realize that in the process they also made a connection to the metal tab, which actually completed the circuit. This was an important point that we had to emphasize to the students and we encouraged them to find other locations that would also work. However, one high school student lit the Christmas tree bulb in this manner, but refused to find other locations that also worked. As a result, this student believed that a light bulb connects only to the base of the socket and did not acquire the correct view that it is connected to the base and the side. Had time permitted, we would have liked to have given this student the one wire task to complete, and to question how those results and the results from the socket related to one another. However, almost all of the students were able to quickly transfer their new knowledge of how the socket connects to a bulb to correct their image of a light bulb's internal wiring.

## Summing It All Up

To summarize, prior research has suggested that students who cannot light a bulb given a single wire, a bulb, and a battery are not able to reason correctly regarding complete circuits. No study to date inquired into how students believe a light bulb is wired. Our research shows that more than half of introductory general education physics students believe that the wires from the filament are connected to only the base of the bulb at the bottom. There appears to be a correlation with the level of the introductory physics course taken (conceptual, algebra, calculus). The reason for this relationship is unclear from our current work, although it may have to do with students' prior experience with light bulbs. Further research would need to be done to uncover the factors influencing this apparent correlation. We have proposed three activities that appear to aid students in developing the correct model of how a light bulb is wired. We recommend their use in high schools and as supplementary activities in the university. We also propose a definition of a complete circuit that classifies a short circuit as a complete circuit, but one that is not advantageous.


### Acknowledgments

This work has been supported in part by NSF Grant # REC-0133621. We would also like to thank Dean Zollman for his insightful comments and suggestions to improve the paper. Lastly, we would like to thank the students and their instructors for participating in the pilot testing of the materials.


### References


1. James Evans, "Teaching electricity with batteries and bulbs," *Phys. Teach.* **16,** 15–22 (Jan. 1978).
2. Lillian C. McDermott and Peter S. Shaffer, "Research as a guide for curriculum development: An example from introductory electricity. Part 1: Investigation of student understanding," *Am. J. Phys*. **60**, 996 (Nov. 1992).
3. Ref. 1, p. 17.
4. Timothy F. Slater, Jeffrey P. Adams, and Thomas R. Brown, "Undergraduate success–and failure–in completing a simple circuit," *J. Coll. Sci. Teach*. **30**, 96–99 (2001); see references 1 and 2.
5. These activities are available by contacting the authors.
6. R.J. Karplus, "Science teaching and development of reasoning," *J. Res. Sci. Teach.* **12**, 213–218. (1974).



PACS codes: 41.71, 01.40Ga, 01.40Gb, 01.40R



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