Fourth Graders' Framing of an Electric Circuits Task

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Abstract. Previous work shows that college students have more difficulty lighting a bulb with a single wire and a battery than with two wires [1], results that have informed the design of activities [2]. We present some unexpected findings from two 4th grade classes engaged in a 15-hour inquiry module on electric circuits. Students successfully lit the bulb with a single wire in a variety of ways, but students from both classes showed and expressed the view that the bulb must be in direct contact with a battery in order for it to light. We suggest this arose from students framing the task as a *building* activity, and we analyze two classroom episodes in support of this interpretation. [1]

Keywords: physics education research, elementary school science, electric circuits, resources perspective
PACS: 01.40.-d, *01.40.eg*, 01.40.Fk, 84.30.-r

INTRODUCTION

As early as the 1970's, physics education researchers have reported that high school and college students have difficulty lighting a bulb with a battery and single wire. Only about half of students evaluated could light a bulb with a single wire on their first attempt [3] [4] [1]. Interestingly, this result holds primarily for 1-wire configurations. Slater et al. [1] found that nearly every student interviewed could light a bulb with a battery and two wires, provided the bulb and battery were mounted in holders. Descriptions of children's performance on the batteries and bulbs task do not directly compare to those of older students, at least in terms of how many wires were used. Tasker and Osborne [5] report that only six of 40 children aged 8-12 could successfully light a bulb, but the researchers do not distinguish between one-wire and two-wire configurations in their classification of the children's solutions.

Many have offered explanations for older students' actions during the battery and bulb task. Fredette and Lochhead [6] suggest that undergraduates conceptualize bulbs as "sinks" capable of drawing electricity via a single connection, explaining why students predict short circuits will light. Engelhardt et al. [7] suggest that student confusion about the inner workings of a bulb could contribute to difficulty distinguishing between lighting circuits and short circuits. From these studies, it would be reasonable to conclude that the two-wire solution is easier, and perhaps that it is conceptually antecedent: students who are able to solve the one-wire problem are able to solve the two-wire problem, but not vise versa.

We present evidence to challenge that conclusion, from two fourth grade classes in which we saw the opposite pattern: students were able to light the bulb with one wire but not with two. We argue that the patterns in students' reasoning should not be understood based purely on conceptual knowledge, but that they arise from complex dynamics that include students' epistemological framing.

THEORETICAL FRAMEWORK

We take a resource-based perspective [8], by which student knowledge and reasoning is a complex system capable of responding in a variety of ways in different situations. The system involves students' rich, varied conceptual resources for understanding physical phenomena and mechanisms [9], as well as epistemological resources [10] for understanding knowledge and epistemic activity. By "epistemological framing" [11], we mean students' sense of what is taking place with respect to knowledge, which we expect involves patterns of conceptual, epistemological, and other resources. For our purposes in this analysis, we focus primarily at the level of framing, rather than at the level of specific resources.

METHODS

We report on findings from an NSF-funded project. Participating teachers attended professional development

[1] This research is supported in part by the National Science Foundation under the grant *Learning Progressions for Scientific Inquiry: A Model Development in the Context of Energy* (DRL 0732233, 01/08-12/11).

meetings to help them recognize and promote students' productive engagement in scientific inquiry. The data presented here are taken from the fourth grade module on electricity, which was implemented by two teachers in the fall and winter of their first year in the project.

The curriculum asked teachers to "give students bulbs, batteries, and wire, and ask them to figure out what ways of connecting them do and do not make the bulb light." It was our hope that this task would provide opportunities for students to eventually pursue mechanistic explanations of electric circuits. Teachers did not intend to evoke a specific framing of the task, and we later inspect individual students' actions rather than teacher actions in making claims about how a student may have been framing the situation.

In Class 1, students worked in pairs with one D cell battery, one flashlight bulb, and two bare copper wires. In Class 2, students were loosely organized into pairs with these same materials, but many pairs coalesced into larger groups to complete the task. We collected the following sources of data: video of students in focus groups working on the activity, video of the teacher interacting with students, video of whole-class discussions, and copies of communal and individual artifacts.

FINDINGS

We look at students' work throughout the opening task–and even into subsequent activities–to gain insights into their evolving use of resources. In both classes, most groups took between five and 25 minutes to reproducibly light the bulb. Students came up with a variety of ways to light the bulb, but effectively all arrangements involved the bulb touching one end of a battery.

In Class 1, the teacher invited students to draw their circuit arrangements on the board, both lighting and non-lighting attempts, as long as they were different from what was already depicted. Although students recorded non-lighting attempts where the battery and bulb were not in direct contact, all but one of the "lights" arrangements (Fig 1) depict the bulb touching the battery.

Given the equipment constraints and commonality in outcome, students demonstrated striking creativity and diversity in their circuits. For example, Circuit B uses one wire to connect battery to bulb and the other wire as a handle to bring the bulb down to the battery and make it light. Circuits C and G orient the battery upside down and sideways. In Circuits A and E two wires are twisted or touched to complete the circuit. Other circuits coil additional wire around the battery (Circuit D) or bulb (Circuit E). Only Circuit H involved two wires. The diversity of arrangements is even more pronounced in Class 2, where student pairs teamed up to share equipment.

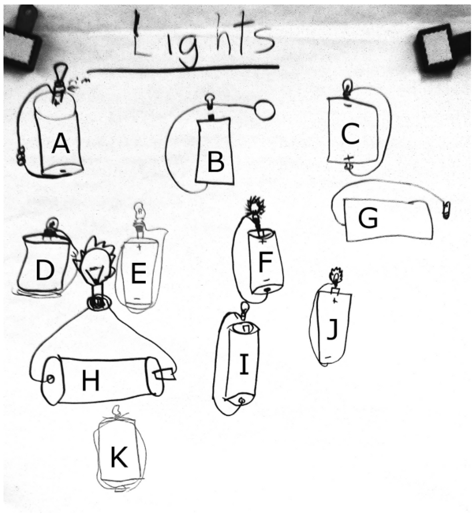

FIGURE 1. Student drawings of arrangements that light the bulb (Class 1, Day 1).

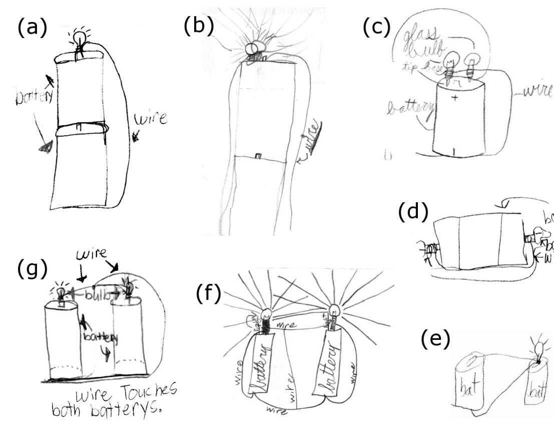

FIGURE 2. Arrangements that light the bulb (Class 2), recorded in students' individual science journals over the course of the module.

Nearly all successful circuits constructed in the opening task, despite the diversity in appearance and application as recognized by the students, required that the bulb be in contact with a battery. In following days, students continued discovering new circuit arrangements, involving multiple batteries in series, additional bulbs in series and parallel, and other conducting materials inserted into the circuit. Figure 2 shows some of these configurations drawn by students in Class 2. Throughout this, the canonical one-bulb circuit–what one student refers to as "the normal way"–involved a single wire connecting the bottom of the battery to the metal threads of the bulb, and the bulb resting on the positive end of the battery, as is depicted in Circuit J of Figure 1.

Later in the module, students expressed the view that the bulb must be in direct contact with the battery. In Class 2, this arose when a guest instructor (the second author) asked students to describe which ways will light the bulb. All of the students' descriptions involved the bulb touching the battery, and when the instructor suggested a standard 2-wire circuit, the class rejected the idea. Several students justified this claim, one student stating: "'cause it [the bulb] has to connect to the top [of the battery]". In Class 1, this view surfaced when students were asked to connect two bulbs in series. Students could reason about the series circuit in terms of drawings and analogy-based models, but were baffled when asked to hook up the equipment. Even the student who drew Circuit H on the first day of the module acknowledged that she was only able to assemble the series circuit after the teacher showed her group how to light one bulb with two wires. We were surprised by this outcome, given the literature on older students' reasoning.

INTERPRETATION

In light of these findings, why were students able to come up with a myriad of arrangements, but not one where the bulb and battery did not directly touch? We propose one aspect of an explanation: students were framing their work with batteries and bulbs as a *building* activity, rather than as an *explaining* activity.

To support this interpretation, we analyze two examples from the students' work with electric circuits. The first demonstrates how the activation of conceptual and perhaps other types of resources could lead students to discover their preferred one-wire circuit more readily than the traditional two-wire circuit. It also shows how extended engagement in the task itself may lead students to increasingly rely on resources other than conceptual resources, reinforcing a framing of the activity as building rather than explaining or experimenting. The second episode exemplifies what students might do after the bulb lights if they continue to frame the task as building: enhance current designs rather than empirically test hypotheses. This may explain why subsequent circuits were functionally similar to the original one-wire discovery.

Example 1: Initial Attempts at Lighting a Bulb. This example comes from a student's first few minutes on the opening activity. The following descriptions are taken from video of the two-person focus group in Class 1:

00:00 min Jessie first coils the wire around the bulb threads, then touches the other end of the wire to the positive terminal of the battery, which is sitting upright on her desk. She coils the other end of the wire around the circular protrusion on the positive terminal of the battery.

In connecting the battery to the bulb via a single wire, Jessie's first attempt implies that something travels from the battery, through the wire, and to the bulb to make it light. Here Jessie may be thinking of this electric circuit in terms of a source-consumer model [12], where batteries are sources of something that is consumed by bulbs to produce light. Therefore Jessie's framing of the task may involve the question, "How do electric circuits work?" However, when success eludes her, her framing of the task increasingly becomes, "What do I have to connect to get this thing to light?" Jessie's actions are guided more and more by resources related to the material affordances of the battery, bulb, and wires:

01:10 min While her partner has the battery, Jessie looks at her bulb. She rubs the metal bottom of the bulb, biting her tongue in concentration, and then says, "Oh, I know!"

...

05:30 min Jessie takes a wire and wraps it around the battery vertically, from the positive terminal around the negative terminal and back up to the positive end. This slips off while she's doing it. She then coils the wire around the middle of the battery like a belt ...

We would not expect, and do not observe in initial attempts here or in the literature [5] [13], students to coil the wire around the outside of a battery. This action does not coincide with common models students employ when reasoning about electric circuits. Instead, it reflects what is easy to do with the equipment provided. Jessie's strategy becomes similar to that of a student in Class 2, who suggests to his partners after many unsuccessful attempts, "Let's just play around with them [the equipment]." In this way, the students' activity focused on identifying conditions by which they could light the bulb, driven more by the possibilities afforded by the materials at hand than by an intuitive sense of mechanism. Having identified those conditions, they did not continue to explore other possibilities in a systematic manner, or to try to account for circuits that did not work, in violation of their expectations. Much as Schauble, Klopfer, and Raghavan [14] found in their study, the students treated the task as one of engineering rather than science, to produce an outcome rather than to explain it.

Example 2: Improving the Circuit. After lighting two separate circuits, another group of students consider design improvements on their circuit rather than develop an explanation for how the circuit works. As the students show the teacher their first working circuit, the following conversation ensues:

Marissa: Hey, I have an idea. We can connect them both.

Skye: *[excited]* Make two. Yeah.

Marissa: We can connect them with the wires and then do it.

Ben: We can use this wire to connect it.

Skye: More power. [Marissa: Yeah!] Or we need to get tape and make it stick so it won't come off.

Ben: Yeah, but then it will waste energy for the battery if you keep it too long.

Marissa: Yeah, but it's a big battery.

The students plan to modify their circuit so that it will coincide with what users may intuitively expect.[2] For example, a user may expect a device to have an on/off switch. Another modification, connecting the two circuits to "make two" rather than one, is a functional improvement rather than an exploration of mechanism. The students are still drawing on resources that would be critical for constructing a mechanistic explanation of electric circuits, but in the context of building; Ben and Marissa reason in terms of the flow and supply of energy, but only in the context of designing an improvement to their existing circuit.

DISCUSSION

There are two differences to note between the fourth graders' reasoning and the results documented in the literature [3] [1] [5]. First, these students were able to light the bulb with one wire more readily than with two, and second, these students were incredulous about the possibility of lighting the bulb without it touching the battery. Our conjecture is that both of these results reflect, in part, the students' epistemological framing of the activity, one closer to engineering than to science [14]. They were able to light the bulb with one wire in part because they were driven more by the affordances of the materials than by their intuitive sense of mechanism.

We are not suggesting that students' conceptual knowledge was entirely uninvolved. The students' initial moves were most likely informed by resources related to a source-consumer model, just as others have concluded [12]. No doubt it "made sense" on first glance to them that the bulb had to touch the battery, perhaps a p-prim [9] for understanding contact as essential for causal connection–you can't push an object without touching it; a frying pan only cooks or burns what it touches. Had they focused their attention on that reasoning, to assess whether it should apply to batteries and bulbs, they might have found reason to doubt it. But they showed no signs of exploring the mechanism further, of trying to connect the causal pattern they observed to their knowledge of other physical mechanisms in the world. Rather, they focused on using their discovery as the basis for further construction, and so the conceptual pattern remained stable. Framing the task as building rather than as explaining may have contributed to the stability of their idea that the bulb must touch the battery.

[2] It is perhaps useful to consider material affordances [15] [16]–these expectations and intuitions about objects and devices–as resources themselves. However, an interpretation of material affordances in terms of a resources perspective is not addressed in this paper.

ACKNOWLEDGMENTS

The authors would like to thank Fred Goldberg for his comments on this paper.

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