Student understanding of DC circuits: fine-grained issues

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Abstract. We report on a study with 60 first year physics students in which we made contextual changes to an "open circuit" in order to measure the effect of such changes to student's responses. The 8 question instrument that we designed included representational, linguistic and (circuit) elemental variations. Our findings indicate that while the changes might appear trivial to an expert they significantly affect the way in which students respond.

1. Introduction

The general experience of teachers and lecturers is that students have difficulties in dealing with basic resistive DC circuits. Many studies have been carried out to probe the nature of these difficulties [1] and a number of interesting teaching approaches have been proposed in response to the research findings. However, it is clear that no single approach has been able to solve all the difficulties [2]. One reason for this may be that both the studies and the proposed solutions are not directed at a fine enough "cognitive grain size" to effect conceptual change [3]. For example, it is common to find (a) studies of student understanding and (b) teaching approaches in which the brightness of light bulb is used as a proxy for current. In doing so there is an underlying tacit assumption that is consistent with the classic "misconceptions" perspective, namely that students have unitary, static, prior conceptions in place. However, as described in [3] this is to be contrasted with the "Knowledge in Pieces" framework in which concepts arise more dynamically from smaller cognitive elements that come together in the moment. Key to this process is the triggering role of context. While the ambit of context is complex the present study confines itself to issues of contextual differences at the level of the circuit itself. In particular we probed the response of students to situations in which seemingly small representational, linguistic and circuit element changes are made, which from an expert point of view should have no bearing on the physics at hand.

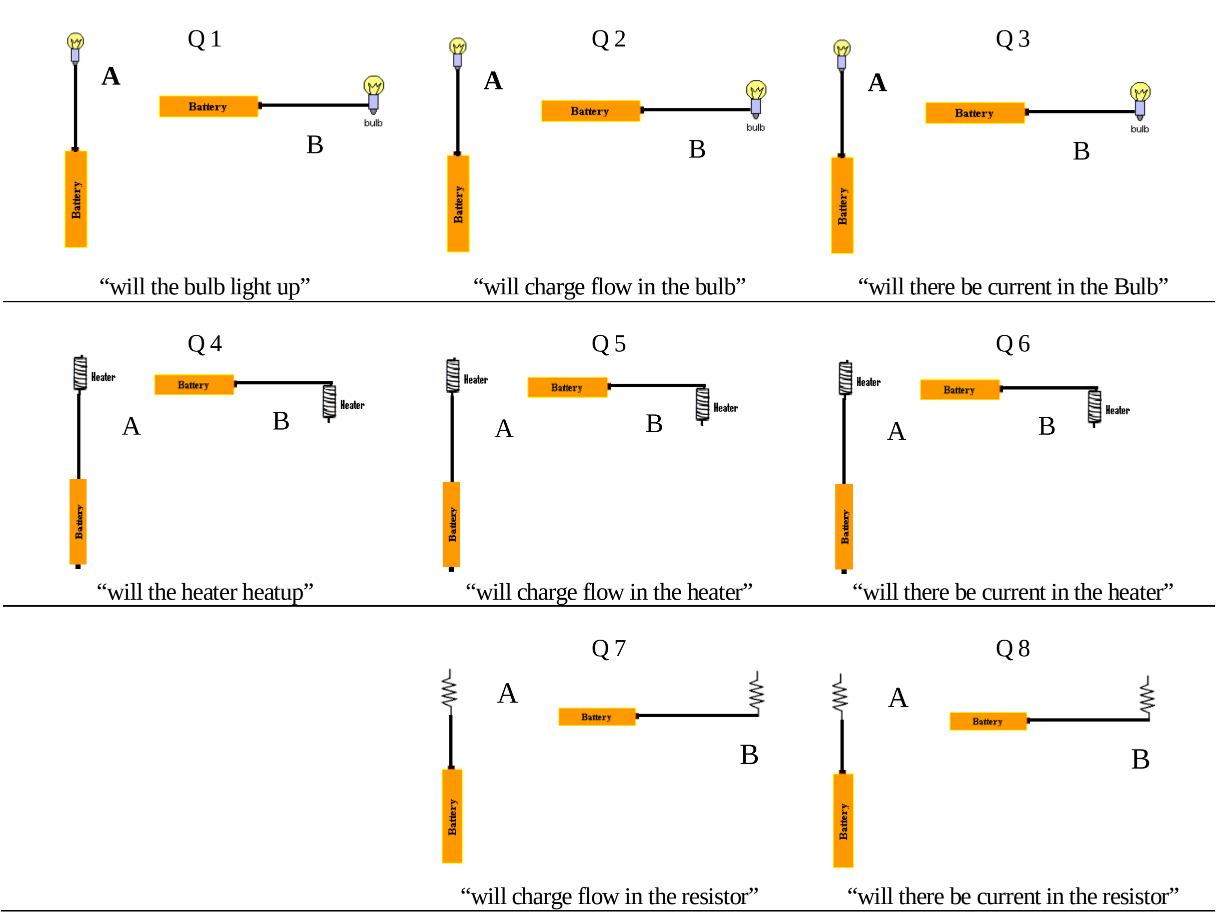
2. Methodology

From a broad range of possibilities we honed in on the areas of question listed below and used these to construct a research instrument that required students' written responses. (a) To what extent does changing a resistor for a light bulb or a heating element affect student response? (b) To what extent does drawing the same circuit vertically or horizontally affects student response? (c) To what extent does the phrase "charge flow" elicit the same response as the term "current"?

2.1. Research Instrument

A series of questions based on an <u>open circuit</u> was developed in which three circuit elements were interchanged with each other, namely, a resistor, a light bulb and a heater. These circuit elements were connected with a single wire to one end of a battery in either a horizontal or vertical configuration. The terms “charge flow”, “current” and “heat up” (or “light up”) were interchanged in the text for identical circuits. Thus, we developed a question bank of 120 questions that spanned the “question space” in a systematic manner. For the purposes of the present study 8 questions were selected as shown in the table 1 below. (Sample question is given in figure 1). The table is arranged so as to facilitate comparison both across the rows and down the columns.

Table 1: The eight questions used in the probe. In the horizontal rows the words are being changed and in the vertical columns the elements are being changed.



The pattern of contextual differences between questions across the rows and the columns can be summarized as follows. With regard to the rows, Row 1 shows 3 questions each consisting of identical scenarios. Each scenario shows two variations of the same circuit, one orientated vertically the other horizontally, comprising one end of a battery connected to a light bulb with a single wire. In the vertical cases the battery is connected to the bottom of the bulb while in the horizontal cases the battery is connected to the side of the bulb. The key variation in each question is the wording of the accompanying text as indicated. Row 2 shows what are essentially the same circuits as in Row 1 but with the bulbs replaced by heaters. In the vertical cases the battery is connected to the bottom of the heater while in the horizontal cases the battery is connected to the top of the heater. The key variation across the row again lies in the text as indicated. Row 3 shows 2 questions each consisting of identical scenarios. Each scenario shows the same circuit configuration but orientated either vertically or horizontally in which one end of a battery is connected to a resistor with a single wire. In both vertical and horizontal cases the battery is connected to the bottom of the resistor. The key variation in each question is the text as indicated. The reason for no scenario being depicted in column 1 is that there is no text that is equivalent to “light up” or “heat up” in the case of the resistor.

If we consider the columns, Column 1 shows 2 scenarios in which the bulb is changed to a heater and the text “light up” is changed to “heat up”, respectively. In addition the point of connection (in the horizontal circuit) to the circuit element is varied from middle (bulb) to top (heater). Column 2 shows 3 scenarios in which the text “is there charge flow” is the same in each case but the circuit element (bulb, heater, resistor) changes. In addition the point of connection to the circuit element is varied (middle-bulb, top-heater, bottom-resistor). Column 3 shows 3 scenarios in which the text “is there current” is the same in each case but the circuit element changes (bulb, heater, resistor). In addition the point of connection to the circuit element is varied (bulb-middle, heater-top, resistor-bottom).

Each question was presented as a situation involving a discussion among a group of students who are posited to be setting up a circuit. A number of different points of view are articulated by the students and offered as options for which (a) a particular option has to be made and (b) the reason for the option has to be provided in detail. In total five options were presented of which the fifth allowed for ideas that were not offered. The response options were presented in a manner that the correct answer was not the same number (1-5) for each question. Figure 1 shows an example of a question in detail.

2.2 Sample

The sample consisted of 60 first year degree students in the extended programs in various courses in the science faculty and was doing Physics1. All these students passed physical science in Grade 12 but they had not received any formal instruction on DC circuits at the university. The majority of the students were from rural schools, aged about 18 years, and for whom English is a second or third language. These students are the first group of students who passed matric in 2008 having followed the new Outcomes Based Education curriculum.

One student connects a light bulb to a battery as shown in figure **A**. Another student connects the light bulb to a battery as shown in the figure **B**. The following discussion takes place among the students.

Student 1 says “The bulb in figure **A** will light up but not the bulb in figure **B**!”

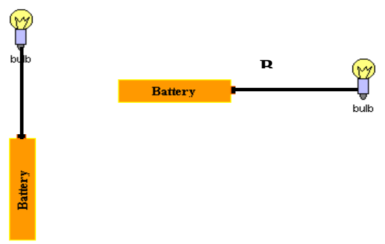
Student 2 says “No! The bulb in figure **B** will light up but not the bulb in figure **A**”

Student 3 says “I disagree! Both bulbs will light up!”

Student 4 says “No! None of the bulbs will light up!”

Student 5 says “I have another idea which I will explain to you!”

With whom do you most closely agree? Circle only one of 1, 2, 3, 4 or 5.



1
2
3
4
5

Explain the reasons for your choice in detail below.

……...

Figure 1: Question format.

2.3 Presentation of the instrument

The questionnaire was presented to the students during a physics practical afternoon session. Students were informed that "we are developing a new curriculum for the 1st years; hence we want to know your basic knowledge in electricity, so that we can develop a suitable curriculum for you. So please answer these questions as sincerely as possible so that we can help you to prepare for your exam". Of the 60 students, Six completed the questionnaire in five minutes while others took more than twenty minutes to complete the questionnaire.

3. Results

Analysis of the data comprised three phases. In the first phase only the numerical choices were analysed while the second phase considered the free response writing and the third is interview. Results from the data in which only the numerical choice was analysed are summarised in table 2. The four different options given in the questions are symbolically represented in the table. The square □ represents option 1: (element in circuit A will activate), the rhombus ◇ represents option 2: (element in circuit B will activate), the triangle △ represents option 3: (elements in circuits A & B will activate) and the closed circle ● represents option 4: the correct answer in that "none of the circuits will activate", since all the circuits are open. Each of the 60 rows in table 2 represents the 8 answers of a particular student.

From the table 2 it can be seen that only 15% of the sample (the first 9 rows of filled circles) chose the correct answers for all 8 questions. In the remaining cases answers can be seen to be changing from one question to another. We then analysed the different types of reasoning used by each student in answering the 8 questions. A number of different lines of enquiry ensued from these results of which we present the following one. Respondents were grouped on the basis of the number of reasons used to explain their answers to the 8 questions. The results were as follows: 12 students used one reason to answer all the 8 questions, 16 students used two reasons, 13 used 3 reasons, 10 used 4 reasons, 6 used 5 reasons and 3 used 6 reasons. The situation is summarised in the bar graph shown in figure 2 where each bar represents the number of students in each group with the number of different reasons cited per individual student.

4. Discussion

In general students who used more than one explanation did not get all the answers correct. Of the 12 students who used only one reason, 9 of them answered all the 8 questions correctly. Eight students of these 9 students who based their reasoning on only one concept appeared to consider the circuit as a whole as the unit of reasoning, using the following words (verbatim)

1. *Incomplete circuit.*
2. *Both positive and negative should be connected.*
3. *Only one end of the battery is connected.*
4. *No circuit.*
5. *No closed circuit.*
6. *Open circuit.*

Thus, only students who explicitly or implicitly used "circuit" reasoning got all 8 questions correct i.e. circuit reasoning provided a productive foothold for dealing with all the situations (light bulb, heating element, resistor, charge flow, current, light up and heat up). In all the other cases where specific features of the context were used as the primary foothold the resulting reasoning ended up with an incorrect conclusion.

Table 2: The eight columns represents the eight answers and each row represents the answers of each student.

St. No.	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
1	●	●	●	●	●	●	●	●
2	●	●	●	●	●	●	●	●
3	●	●	●	●	●	●	●	●
4	●	●	●	●	●	●	●	●
5	●	●	●	●	●	●	●	●
6	●	●	●	●	●	●	●	●
7	●	●	●	●	●	●	●	●
8	●	●	●	●	●	●	●	●
9	●	●	●	●	●	●	●	●
10	□	●	●	●	●	●	●	●
11	□	●	●	●	●	●	●	●
12	△	●	●	●	●	●	●	△
13	●	●	●	●	◇	●	●	●
14	●	●	●	●	◇	●	●	●
15	●	●	●	●	●	◇	●	
16	●	●	●	●	△	●	●	□
17	●	●	●	●	●	◇	●	●
18	●	●	●	●	●	△	●	△
19	△	●	●	●	●	◇	●	△
20	●	□	△	●	△	●	●	●
21	●	●	△	△	●	●	△	●
22	●	●	●	●	●	●		△
23	●	●	□	□	□	●	●	●
24	□	●	◇	●	□	●	●	●
25	△	△	△	●	●	●	●	●
26	△	●	●	□	△	●	□	△
27	●	●	△	◇	△	△	△	●
28	●	□	●	●	△	●	◇	△
29	△	◇	●	△	●	●	◇	●
30	□	◇	△	□	△	●	●	●
31	□	●	△	□	△	●	●	□
32	●	●	●	●	△	△	●	△
33	□	◇	●	□	●	s	●	□
34	△	△	s	●	△	△	●	△
35	●	□	△	△	s	●	◇	●
36	●	□	□	△	△	△	●	△
37	△	△	s	●	△	□	●	△
38	●	●	□	□	△	◇	◇	□
39	△	△	●	□	◇		◇	◇
40	△	△	△	△	△	△	△	●
41	□	△	△	□	△	△	●	△
42	□	s	◇	□	△	□	●	●
43	△	◇	△	s	△	△	●	□
44	□	●	△	□	△	◇	●	□
45	△	△	△	△	△	△	△	△
46	□	△	△	□	△	△	△	□
47	●	●	△	□	s	s	◇	s
48	□	△	△	□	●	△	△	□
49	△	◇	△	△	△	◇	◇	△
50	□	△	△	□	△	△	△	□
51	△	◇	△	□	△	◇	◇	□
52	△	△	△	●	△	△	△	●
53	△	△	△	●	△	△	△	●
54	△	△	△	△	△	△	△	△
55	□	△	●	□	△	△	□	□
56	□	◇	△	△	△	◇	◇	△
57	□	◇	◇	□	□	◇	◇	□
58	□	△	△	□	△	△	△	□
59	△	s	△	△	●	△	△	△
60	□	◇	△	□	△	◇	△	□

In keeping with the "Knowledge in Pieces" framework, individual student reasoning about circuits depended strongly on contextual cues provided by the type of circuit elements, the words used and point of connection to the light bulb i.e. bottom or side. A number of curious conceptions also surfaced amongst the reasons provided. For example, regarding resistors, ideas included that a resistor is a device that is used to connect different elements in the circuit, to notions that the resistor stores electricity or is used to stop current. It is possible that students are engaged in local sense-making (and there is anecdotal evidence to suggest this) but direct interviews will be necessary to probe these aspects further. A key point of interest that also requires further elaboration is to try and understand which contextual features trigger starting points for reasoning. This will almost certainly influence the design of future teaching approaches.

However, it is already suggestive from the present results that any curriculum for teaching circuits will need to address prior experience in a manner that turns it into a productive cognitive resource. What seems to be clear at this stage is that the use of light bulbs in both the teaching of DC circuits and probing student understanding requires closer scrutiny.

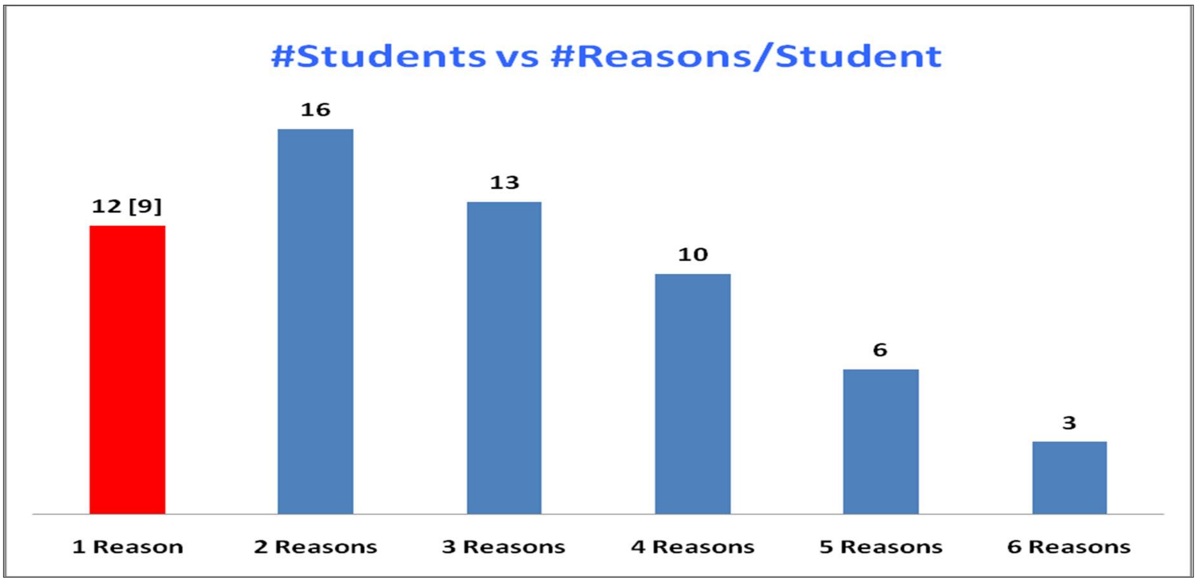


Figure 2: The number of students in six groups with different number of reasons.

References

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