DC Circuits: Context Dependence of Student Responses

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Abstract. We report on a study with first year university physics students in which we investigated the effect on student responses when small contextual changes were made to the presentation of an "open circuit". The eight question instrument that we designed included representational, linguistic and circuit element variations. Our findings indicate that while the changes might appear trivial they significantly affect the way in which students respond.

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INTRODUCTION

It is a common experience that students have difficulty in dealing with basic DC circuits. Many studies have been carried out to probe the nature of these difficulties and many curricula try various innovative approaches to introduce the topic. See for example [1, 2]. However, it is not clear that the underlying reasons for these difficulties are clearly understood or that the issues are being addressed at a fundamental level. In particular, the degree of sensitivity to seemingly trivial contextual changes has not been well researched in a systematic manner.

For example, in many studies it is assumed that using the brightness of a light bulb as a proxy for current leads to results that can be generalized insofar as DC circuits are concerned. While this conclusion may indeed be consistent with a classic "misconceptions" view it is not clear that this is true from a "knowledge in pieces" perspective in which context and cognitive "grain-size" are key components. A comparison of these contrasting approaches can be found, for example, in [3].

METHODOLOGY

In the present study we investigated to what extent seemingly small contextual changes to a DC circuit affected students' responses. We focused on the following three aspects: (1) changes between equivalent resistive elements (2) changes to the circuit orientation and (3) changes to wording.

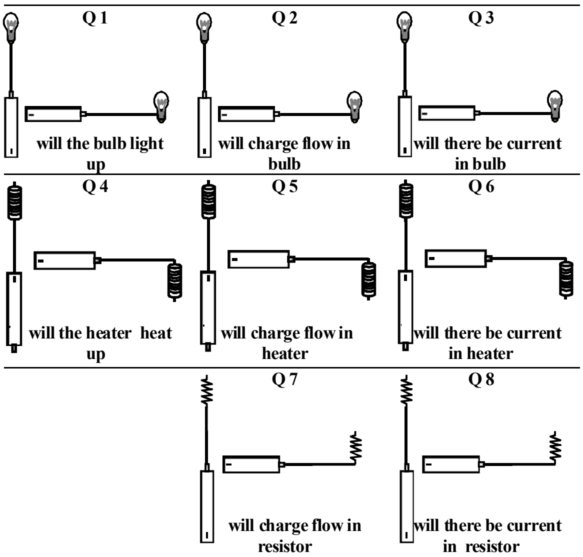
A series of questions based on an open circuit was developed in which three circuit elements were interchanged with each other, namely, a resistor, a light bulb and a heater. These circuit elements were connected with a single wire to one end of a battery in either a horizontal or vertical configuration. In the case of the horizontal configuration the circuit element was connected either to the bottom, side or top. The vertical configuration always showed a connection to the bottom of the element. In addition the terms "charge flow", "current" and "heat up" (heater) or "light up" (bulb) were also interchanged in the text. The eight questions used in the study, each comprising the same circuit in both vertical and horizontal orientations, are shown in Table 1. The table is arranged so as to facilitate comparison across rows and down columns: thus, across the rows the key variation is the wording ('light up', 'heat up', 'charge flow', 'current') while the key variation down a column is the circuit element (light bulb, heater or resistor). The reason for the empty entry (column 1 row 3) is that there is no appropriate text equivalent to "light up" or "heat up" in the case of the resistor.

Each question was presented as a hypothetical situation involving a discussion among a group of students setting up a circuit. A number of different points of view are articulated by the 'hypothetical students' and offered as answer options. For each question the student taking the questionnaire had to: (1) choose one point of view and (2) provide a detailed reason for choosing that particular point of view. Fig. 1 shows the form of a question in detail.

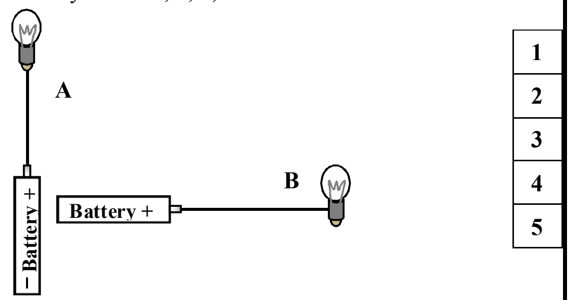
STUDENT COHORT

The cohort that we report on comprised 60 first time entering university students, predominantly 18 years old. All these students graduated from high school with physical science (a combination of physics and chemistry) as one of their high school subjects. Electricity, including DC circuits, forms part of the physical science curriculum which is examined at the end of grade 12 in a common national examination.

TABLE 1. Summary of the 8 questions used in the study.



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.



Explain the reasons for your choice in detail below.

FIGURE 1. Detailed format of a typical question.

ANALYSIS OF ANSWER CHOICES

The first phase of the analysis involved tallying the answer choices of the cohort for each question. Since all the circuits under consideration are "open" there is no current in any of the circuit elements and neither the bulb nor the heater will activate. (For convenience we will also use the term "activate" for current or charge flow in the resistor).

Fig. 2 summarizes the responses for the cohort for each of the eight questions in detail. Vertically shaded bars show the percentages of students who chose the view that a *vertical circuit activates*; horizontally shaded bars show the percentages of students who chose *horizontal circuits will activate* while the diagonally shaded bars represent the students who chose the view that *both vertical and horizontal circuits will activate*. The grey solid bars indicate the percentages of students who chose *none of the circuits will activate* (correct answer). The percentages shown per question do not include a small number of "non-responses" so not all total to 100%. From the figure it can be seen that for each question roughly half of the group chose the option that the circuit element in question would not activate in either circuit orientation. While it is not possible to discuss the features of the distribution in any detail it is clear that contextual factors play a significant role. Here we only point out two interesting cases where the responses are significantly different (95% CI): (1) the highest correct response (57%) was obtained for the question involving current through the heater while the lowest was obtained for the question regarding charge flow though the resistor (38%) and (2) while 48% of the group responded that charge would flow in both cases with regard to the resistor only 17% thought that both light bulbs would have current in them.

A detailed student by student analysis was also carried out in which the eight responses from each student were analyzed. The finding from this exercise was that only 15% of the cohort chose the point of view that none of the circuit elements would activate for all eight questions. Thus, in general the vast majority of students viewed one or more situations differently to the way in which an expert would. In addition hardly any students chose the same (incorrect) answer consistently across the eight questions. These interesting results were explored in greater depth during the following phase of analysis as described below.

ANALYSIS OF FREE WRITING RESPONSES

In the second phase of the study we analyzed the free writing responses that were elicited by the request to provide detailed reasoning for the answer choice. The analysis proceeded as follows: Each piece of writing was first summarized in a

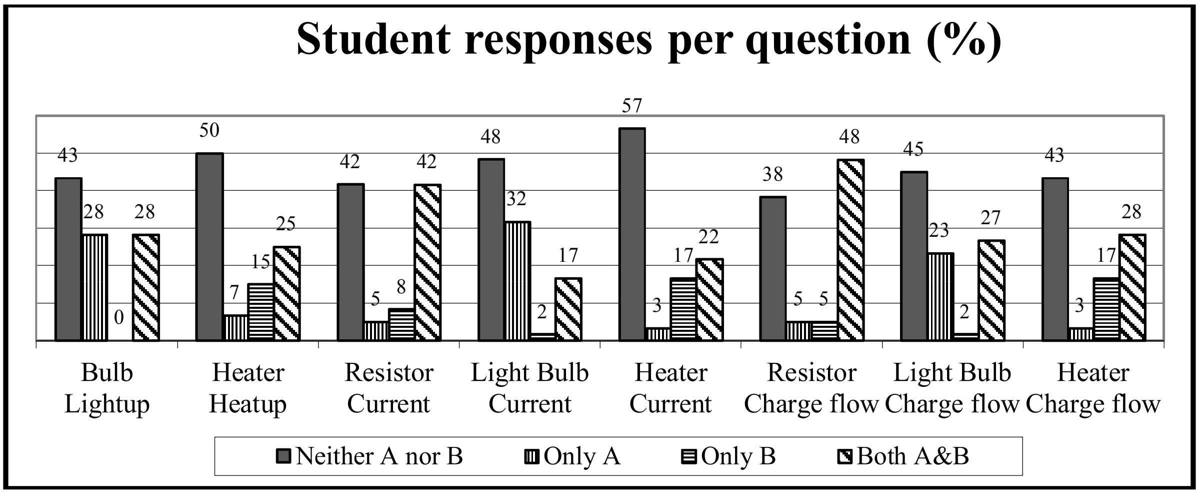


FIGURE 2. Student responses to each question regarding whether the circuit element under consideration will activate. A and B in the key indicate the vertical and horizontal orientations of the same circuit, respectively.

short form that captured the essence of what the student had written without interpretation. (We shall call this a 'summarized written response' or SWR). This was necessary as the responses of the students were often long winded and difficult to read due to either poor handwriting or language used. The exercise was carried out by one researcher after which a random sample of 10 students per question was selected and the SWR compared with the original student writing. In all cases it was confirmed that the SWR faithfully captured the original writing. Based on the SWR the key idea being expressed was then noted. A sample of 20 students per question was completed independently by two researchers whose agreement on the key idea that was being used in the reasoning was over 90%.

By way of illustration Table 2 shows the reasoning of a particular student who obtained 5 correct answers (1,2,4,6,7) from the answer choice perspective. It is clear from 1, 4, 6 and 7 that a *key idea* used by the student to explain why circuit elements do not activate is that *the circuit is not complete.* This is explicitly stated in 4, 6 and 7 while in 1 the idea is implied but clear if read in conjunction with 4. Another key idea (from 2 and 5) is that *charge flows only from negative to positive*. In general the student used either "the circuit" or "charge flow" as the starting point for their explanation. It is not immediately clear, however, as to what contextual feature triggers the one or the other as question 6 which explicitly uses the term "charge flow" in the question engendered the explanation "the circuit is incomplete"!

DISCUSSION

The data we have taken and analyzed to date show for the apparently simple case of an open DC circuit consisting of little more than a battery, a connecting wire and a resistive circuit element, that fine-grained contextual cues appear to play a large role in guiding the response of the students. The analysis of the answer choices on their own (fig. 2) clearly demonstrates the range of responses that are triggered by seemingly small changes to the questions.

While the analysis of the free writing responses was highly illuminating on the whole it was not always straightforward to attribute which particular contextual aspect was used as the starting point for engaging with the question. This is apparent from the example in Table 2. However, from the range of written responses two somewhat different categories emerged.

The first category involves what appears to be various surface level misunderstandings, possibly due to prior formal learning, such as the apparent confusion between current and charge flow as in Table 2 or as another example, that a circuit "is incomplete without a switch" (and hence the circuit elements will not activate). The second category is speculated to be tied to students' firsthand experience such as connecting a light bulb into a socket or observing that most electronic devices work only when the batteries are inserted with the correct polarity.

At a more descriptive level we note that none of the students who used more than one (key) idea across the eight questions got all eight questions correct. On the other hand only those students who expressed the single idea of an "incomplete circuit" or words to that

TABLE 2. Summarized written responses of a student.

Question Number	Question	Answer Chosen	Summarized Written Response
1	Will the bulbs light up?	None of them will light up.	Since both bulbs are connected to only one end.
2	Will there be current in the bulbs?	None of them will have current.	Since charge will flow only from negative to positive.
3	Will charge flow in the bulbs?	Both bulbs will have charge flow.	Since charge will flow from the battery, but bulb will not light up.
4	Will the heaters heat up?	None of the heaters will heat up.	Since only one end is connected to the battery, the circuit is not complete.
5	Will there be current in the heaters?	There will be current in vertical circuit, but not in horizontal.	Since charge will flow from negative to positive terminal, but not the other way around
6	Will charge flow in the heaters?	None of the heaters will have charge flow.	Since the circuit is incomplete.
7	Will there be current in the resistors?	None of the resistors have current.	Since circuits are not complete.
8	Will charge flow in the resistors?	Both resistors will have charge flow.	Charge will flow into the resistor and dissipate in the resistor as it cannot return to the battery.

effect chose the correct answer in each case. However, as noted in the previous paragraph the notion of what constitutes a complete or incomplete circuit may not necessarily be correct. It is issues such as these as well the need to try and identify the contextual triggers at work and the consequences for the reasoning that follows that require exploration by interviews.

Thus, as a follow-up to the work reported here we have started to interview a sample of students based on their written responses. While the results from these interviews are not the subject of the present paper we found it surprising (and encouraging) that in many cases it was students' attempts to use previous sense-making episodes as the basis for their reasoning that often lead to incorrect conclusions for various reasons rather than that they were trying to recall by rote.

In conclusion we have shown that students' responses to questions about a simple DC circuit appear to be strongly dependent on contextual issues. These findings would appear to have implications for both the interpretation and the generalization of research findings that use only one context such as a light bulb when probing student understanding of DC circuits.

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