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Sequential Reasoning in Electricity: Developing and Using a Three-Tier Multiple Choice Test

Hildegard Urban

Abstract

Electricity is one of the areas in physics most studied in terms of learning difficulties. Misconceptions are strongly-held, stable cognitive structures, which differ from expert conception and affect how students understand scientific explanations. Therefore, there is a need for tests of conceptual understanding tests which are useful in diagnosing the nature of students' misconceptions related to simple electric circuits and, in consequence, can serve as a valid and reliable measure of students' qualitative understanding of simple electric circuits. As ordinary multiple choice tests with one-tier may overestimate the students' correct as well as wrong answers, two- and three-tier tests were developed by researchers. Although, there is much research related to students' conceptions in basic electricity, there is a lack of instruments for testing basic electricity concepts of students at grade 7, especially addressing an electric circuit as a system for a simple circuit of resistors and lamps in series. To address this gap, the context of the present study is an extension to the development of an already existing instrument developed by the author for testing electricity concepts of students at grade 7, specifically focusing on only two specific aspects in depth: first, to develop three-tier items for figuring out sequential reasoning, and second, to distinguish between misconceptions and lack of knowledge. The participants of the study included 339 secondary school students from grade 7 to 12 after instruction on electricity. Surprisingly, there are no dependences on students' misconceptions either according to their gender or to their age. In conclusion, the findings of the study suggest that four items for uncovering students' sequential reasoning can serve as a valid and reliable measure of students' qualitative understanding of the systemic character of an electric circuit.

Key words: three-tier concept test, sequential reasoning in electricity, uncovering students' conceptual understanding.

Theoretical background

Research findings suggest that there are three categories of student difficulties in basic electricity: inability to apply formal concepts to electric circuits, inability to use and interpret formal representations of an electric circuit, and inability to qualitatively argue about the behavior of an electric circuit (McDermott & Shaffer, 1992). In general, students come to the classroom with various misconceptions which may critically influence their understanding of scientific concepts and explanations (Hammer, 1996). In other words, students may have various, often pre-conceived misconceptions about electricity, which stand in the way of learning. The most two resistant obstacles seem to be to view a battery as a source of constant current and to not consider a circuit as a system (Dupin & Johsua, 1987). Closset introduced the term *sequentialreasoning* which appears to be widespread among students (Closset, 1983; Shipstone, 1984). There is some evidence that sequential reasoning at least partially is developed at school (Shipstone, 1988) and reinforced by the teacher (Sebastia, 1993). Using the metaphor of a fluid in motion (Rosencwajg, 1992) and highlighting that electricity leaves the battery at one terminal and goes to turn on the different components in the circuit successively does not support students in viewing a circuit as a system (Brna, 1988) On the contrary, this linear and temporal processing prevents students from making functional connections between the elements of a circuit and from viewing the circuit structure as a unified system (Heller & Finley, 1992). Surprisingly, research findings do not indicate a different development of sequential reasoning according to age (Riley, Bee & Mokwa, 1981). Similar conceptions are also held by adults and some teachers (Bilal & Erol, 2009).

Therefore, there is a need for a diagnosis instrument to get information about students' preconceptions and also to evaluate the physics classroom. In order to identify and measure students' misconceptions about electricity different approaches have been made. In contrast to interviews, diagnostic multiple choice tests can be immediately scored and applied to a large number of subjects. Pesman and Eryilmaz (2010) used the three tier test methodology for developing the SECDT (Simple Electric Circuits Diagnostic Test). In order not to overestimate students' right as well as wrong answers, researchers developed two- and three-tier tests (Pesman & Eryilmaz, 2010; Urban-Woldron & Hopf, 2012). Starting from an ordinary multiple choice questions in the first tier, students are asked about their reasoning in the second tier, and students estimate their confidence in their answers in the third-tier.

An extensive review of literature according to appropriate test instruments showed that they either did not achieve psychometric requirements or were developed only for high school or college students. In view of a lack of instruments for testing electricity concepts of students at grade 7 and for being suitable for the Austrian physics curriculum, the author developed a diagnostic instrument with some two-tier items for assessing students' conceptual understanding as well as its potential use in evaluating curricula and innovative approaches in physics education (Urban-Woldron & Hopf, 2012).

Aim and Research Question

Many students seem to be unable to consider a circuit as a whole system, where any change in any of the elements definitely affects the whole circuit. In consequence, they often demonstrate 'local reasoning' by focusing their attention only on one specific point in the circuit and by ignoring what is happening elsewhere in the circuit. In circuits with resistors in parallel students often believe that the current is divided into two equal parts at each junction neither taking into account the values of the resistors nor concentrating on the whole number of resistors. Additionally, students show ‘sequential reasoning’, by which they believe that for example, if a resistor in a circuit is replaced by a resistor with higher value, only elements coming after the resistor are affected.

For gaining a correct vision of student understanding, it is crucial to discover what students actually do not know and what kind of alternative conceptions they have. Therefore, also for the researcher the wrong answers and the associated explanations of the students are much more interesting and usable than the correct answers. Consequently, the context of this study is an extension to the development of an already existing instrument for testing the concepts of electricity of students at grade 7 in two specific aspects: first, to develop items for figuring out sequential reasoning, and second, to distinguish between misconceptions and lack of knowledge. The following broad research question was addressed:

Can a three-tier multiple choice test be developed that is reliable, valid, and uncovers certain students’ misconceptions related to sequential reasoning?

Method

In order to develop a reliable tool to identify students’ misconceptions related to sequential reasoning and in addition to previous studies (Urban-Woldron & Hopf, 2012), the author first conducted interviews based on a literature review, using both structured and open-ended questions. In an initial stage a 10-item questionnaire was developed, including 10 two-tier items (meaning question plus follow-up question, an example is provided in Figure 1). Subsequently, only four out of those ten items finally constituted the test instrument used in this present study, assessing students’ understanding of the systemic character of a simple electric circuit with three-tier items.

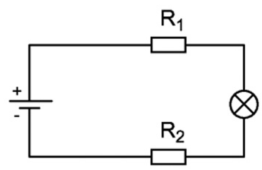
<table>
<tr><td colspan="4">A lamp and two resistors are connected to a battery.</td></tr>
<tr><td colspan="3">a) What will happen to the brightness of the lamp if R_1 is increased and R_2 remains constant?</td><td rowspan="5"></td></tr>
<tr><td colspan="3">☐ The brightness of the lamp decreases.</td></tr>
<tr><td colspan="3">☐ The brightness of the lamp remains constant.</td></tr>
<tr><td colspan="3">☐ The brightness of the lamp increases.</td></tr>
<tr><td colspan="3">b) How would you explain your reasoning?</td></tr>
<tr><td colspan="4">☐ It is the same battery. Therefore, the same current is delivered.</td></tr>
<tr><td colspan="4">☐ A change of the resistor only influences the brightness of the lamp if the lamp is behind the resistor.</td></tr>
<tr><td colspan="4">☐ Any change of the resistor influences the brightness of the lamp independently of its position in the circuit.</td></tr>
<tr><td colspan="4">c) Are you sure about your answer to the previous two questions?</td></tr>
<tr><td>☐ highly certain</td><td>☐ rather certain</td><td>☐ rather uncertain</td><td>☐ highly uncertain</td></tr>
</table>

Figure 1: Sample Item A

In the first round of evaluation with 10 teachers and 113 students (grade 8, 58 female), the questionnaire was reduced to 7 items, each extended with a third tier asking for students‘ confidence in answering each question. After a test run with 339 students of grade 7 to grade 12 from secondary schools across Austria following formal instruction (183 female, mean age 14.7 years, standard deviation 1.7 years) results were evaluated with the software programs SPSS and AMOS. In a polishing round, additional interviews were used to optimize the test items. To get the score for a two-tier item, a value of '1' was assigned when both responses were correct. Furthermore, by examining specific combinations of answers other relevant variables werecalculated to address students' misconceptions. Finally, for constituting the latent variable "sequential reasoning", four items were used.

In the following, we present a three-tiered item (see Figure 2), asking questions related to very simple electric circuits; as we will see, there is ample space for misconceptions despite their simplicity. We need to add here that the answers provided have not been thought up by the researcher but are based both on literature review (Dupin & Johsua, 1987; Closset, 1983; Shipstone, 1984, 1988) and clarifying interviews with students.

Participants and Setting

The participants of the study included 339 secondary school students from grade 7 to 12 (183 female; mean age = 14.7 years, SD = 1.7; 18 forms, 7 schools) after instruction on electricity. Nine teachers were randomly asked to administer a paper and pencil test to their students with 7 three-tiered items related to sequential reasoning. Figure 2 shows the distribution of the students amongst grades.

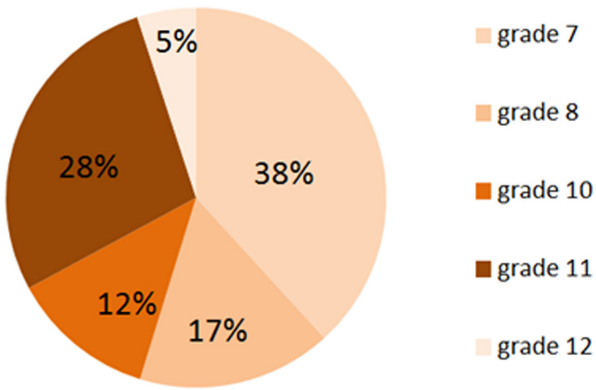


Figure 2: Distribution of students and grades

Data Analysis

Starting with descriptive analyses, analyses of variance, confirmatory factor analyses, and regression analysis using the software SPSS and AMOS were conducted.

Results

Obviously, the correct answer for item A (see Figure 2) would be a1 and b3. 108 students out of 323 who answered all four items (33.4 %) provided a correct answer to the first two tiers of item A.A closer look at the numbers in table 1 shows that 51.7 % or 167 students actually answered the first tier correctly, but 59 out of these

167 students or 35.3 % provided a wrong reason. Consequently, more than one third of the correctly responding students on the first tier can be added to so-called false positives. On the other hand, 153 students chose the right explanation, whereas only 70.6 % of these students also gave a correct answer on the first tier. Therefore, we critically overestimate students' knowledge if we only look at one tier. Overall, 30 students are highly certain, 105 are rather certain, 88 are rather uncertain, and 100 are highly uncertain about their answers. 11 of the highly certain students and 27 of the rather certain ones give the correct answer for the first and the second tier, whereas only 8 of the highly uncertain students answer this item correctly. In other words, the results suggest that some students may be presumably guessing and sometimes they indeed guess right on both sections. Consequently, if we want to completely exclude guessing anyway we have to focus only on students with high certainty reported.

Table 1 gives an overview of the three answer options a1, a2, and a3 and the three associated alternatives b1, b2, and b3 for the reasoning.

Table 1: Distribution of answers and reasons for item A

	a1	a2	a3	
b1	4	49	1	54
b2	55	36	25	116
b3	108	7	38	153
	167	92	64	323

Next, three misconceptions which were derived connecting specific answers and explanations will be illustrated here:

Misconception #1 (Answers a1, b2)

In this misconception the student chooses the right answer, but based on the observation that the lamp is behind the resistor when electricity is moving round the circuit from the positive to the negative terminal. More than a third of students who identified that the bulb will be dimmer gave this erroneous explanation. This is a prime example that a correct test answer is not yet proof that the student had really understood the underlying concept.

Misconception #2 and #3 (Answers a2, b2 or b1)

Here, the student probably thinks that a constant amount of current leaves the battery at the negative end and reaches the lamp before it arrives at the increased resistor. 36 out of 92 students think sequentially. 49 students out of those 92 view the battery as a source of constant current not considering any influence from the resistance on the intensity of current. 38 students respond in a false-negative way as they choose the correct explanation but think that an increased resistor produces an increased brightness of the lamp.

Construct validity was evaluated through factor analysis. Confirmatory factor analysis with AMOS, using the maximum-likelihood-method and including specific combinations of answers due to the first and second-tier of four different test items, resulted in a χ^2-value of 5.805, which was not significant ($p = .221$). Therefore, a latent variable 'sequential reasoning' could be established (see Figure 3).

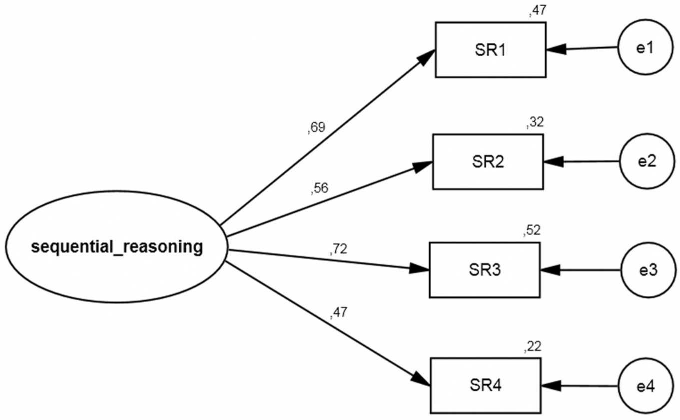


Figure 3: Latent Variable 'sequential reasoning'

As mentioned above, students from 18 forms in 7 schools took part in the study. Consequently, nine teachers were involved. Findings from ANOVA reveal a main effect for correct answers concerning all four items A to D on the particular school, respectively on the particular teacher. Surprisingly, there are no dependences on students' conceptions both related to correct answers and misconceptions neither according to their gender nor to their age.

Furthermore, regression analysis, where items A to C[1] were used to predict sequential reasoning for item D, suggests that those three factors together explain 31 % of the variance for item D ($F(3, 338) = 49.89$, $p < .000\,1$) and are significant individual predictors of students' sequential reasoning for item D (see Figure 4).

A resistor and two lamps are connected to a battery.

a) What will happen to the brightness of the lamps if R is increased?

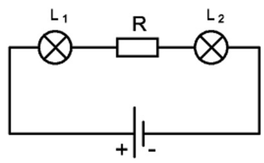
☐ L_1 remains constant, L_2 decreases.

☐ L_1 decreases, L_2 remains constant.

☐ The brightness of both lamps increases.

☐ The brightness of both lamps decreases.

☐ The brightness of both lamps remains constant.



b) How would you explain your reasoning?

☐ A change of the resistor only influences the brightness of the lamp if the lamp is behind the resistor.

☐ Any change of the resistor influences the brightness of both lamps.

☐ It is the same battery. Therefore, the same current is delivered.

☐ Both lamps have a direct connection to the battery. Therefore, the resistor has no effect on the lamps.

c) Are you sure about your answer to the previous two questions?

☐ highly certain	☐ rather certain	☐ rather uncertain	☐ highly uncertain

Figure 4: Item D

[1]Colleagues interested in items B and C are encouraged to ask the author.

Conclusions and implications

In conclusion, the findings of the study suggest that four items for uncovering students' sequential reasoning can serve as a valid and reliable measure of students' qualitative understanding of the systemic character of an electric circuit. Obviously, if researchers or teachers use only one tier in a multiple choice instrument, they definitely overestimate correct answers and in consequence, gain of a wrong impression of student understanding. The present instrument can be used as a tool both for teachers and researchers to gain a correct vision of student understanding. It can be easily administered to a large number of students and could be used as a research tool for assessing new curriculum materials or teaching strategies. Although there is some evidence that the conceptual test is reliable, valid and objective, there have to be a few improvements. Additional interviews highlighted that the wording on the first tier may not be perfectly comprehensible to students. A student may be very confident about his or her answer on the third tier but not about his or her given explanations on the second tier. Furthermore, the interviews which were carried out to develop the distractors for the explanations revealed that some of the teachers tend to introduce the direction of the current from the positive to the negative terminal of the battery, whereas others use the direction of the negative charges from the negative to the positive pole. Therefore, further improvements of the conceptual test instrument will take these limitations of the present study into consideration by using an arrow to indicate the direction of the current.

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Hildegard Urban
University College of Teacher Education Lower Austria