Results of a Design-Based-Research study to improve students' understanding of simple electric circuits

Jan-Philipp Burde, Thomas Wilhelm

Department for Physics Education Research, Goethe University Frankfurt, Max-von-Laue-Str. 1, 60438 Frankfurt am Main, Germany

Effective reasoning about electric circuits requires a solid understanding of voltage and potential. However, most students fail to correctly analyze electric circuits as they tend to reason exclusively with current and resistance. Therefore, a new curriculum based on the electron gas model was developed and empirically evaluated in a study with 790 students from Frankfurt, Germany. The study followed a pretest-posttest-control-group-design and used a recognized two-tier diagnostic test instrument, which also allowed evaluating common alternative conceptions. The results of the empirical study show that the new curriculum leads to a significantly better conceptual understanding than traditional teaching approaches in Germany.

1 Motivation

Despite many years of science education, students often do not develop the ability to reason qualitatively about electric circuits. Instead, they tend to resort to algorithmic manipulations when analyzing simple circuits as the mathematical introduction of Ohm's law often precedes a robust conceptual understanding of its underlying physical quantities [1]. However, even when considerable time is spent on developing a qualitative understanding of electric circuits, research on students' conceptual difficulties in electricity shows that voltage and electric potential typically remain unlearned even after instruction [2]. A particularly widespread alternative conception in this context is that voltage is seen as a property or as a component of an electric current rather than an independent physical quantity that refers to a difference in electric potential [3]. Not realizing the importance of voltage as the cause of the flow of current, students tend to reason exclusively with current and resistance when analyzing electric circuits.

2 The New Curriculum

Taking into account the results from earlier studies on typical alternative conceptions in electricity and previously successful teaching concepts [4], a new curriculum including appropriate course materials was developed for secondary schools. The primary objective of the new curriculum is to give students a qualitative but robust conception of voltage, current and resistance and to help them overcome typical alternative conceptions. It constantly endeavors to provide students with intuitive explanations that have their origins in their everyday physical intuitions. A prototype conception of the electric potential is therefore introduced by comparing it with air pressure. At the example of hands-on experiments (e.g. with bicycle tires or air mattresses) students learn that air always flows from areas of high pressure to areas of low pressure and that pressure differences are the cause for an air flow. This idea is then transferred to electric circuits, where voltage is consequently introduced as an electric pressure difference and as the causal agent of current propulsion just as air pressure differences are the cause of air flow. Similarly, the concept of electric resistance is introduced in analogy to a dense fabric cushion impeding the airflow. In contrast to traditional teaching approaches, the focus does not lie on the electric current itself, but on potential difference as the cause of the electric current from the very beginning. For this reason, the electric potential and potential differences are introduced even before the electric current.

3 Sample and Test Instrument

The quasi-experimental field study followed a pretest-posttest-control-group design and was based on the testing of N = 790 students from Frankfurt/Main, Germany. The control group (CG) consisted of 17 junior high school classes and a total of N = 357 students. The slightly larger experimental group (EG) consisted of 19 junior high school classes and a total of N = 433 students. In both groups, the same valid and reliable two-tier diagnostic multiple-choice test was used for the pre- and posttest [5]. The advantage of the two-tier structure of the test is that students have to justify and explain their answers. This not only allows the identification of false-positive answers (i.e., correct answers despite an inadequate explanation), but more importantly, the identification of typical alternative conceptions about electric circuits.

4 Empirical Results

One way to compare the net effect of instruction is to compare the difference between the pre- and posttest results of the two groups. On average, the absolute achievement gain by students who were taught according to the new curriculum (M = 6.70, SE = .26) is almost twice as high as that of traditionally taught students (M = 3.54, SE = .24). A mixed ANOVA with time of measurement (pretest, posttest) as a within-subjects factor and group (CG, EG) as between-subjects factor shows that the difference in absolute achievement gain between EG and CG is highly significant. A more advanced analysis of the data using a Hierarchical Linear Model (HLM) shows that the net effect of instruction is $d = .94$, which represents a large effect. It can therefore be assumed that the new curriculum leads to a significantly higher learning progress than traditional physics lessons.

Thanks to the two-tier structure of the test instrument, it was also possible to evaluate the students' alternative conceptions after instruction. In general, the new curriculum seems to lead to a better conceptual understanding as students of the EG either have a comparable or significantly lower probability to hold typical alternative conceptions after instruction than traditionally taught students. A comparison of students' conceptual understanding of voltage after instruction suggests that the new curriculum leads to a better understanding of voltage than the traditional approaches.

5 Conclusion

In summary, it can be said that the new teaching concept developed and evaluated in this study has proven to be a promising approach to teaching electricity in secondary schools. The presentation will report in more detail on the key findings of the empirical study as well as the ideas behind the new teaching concept.

References

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