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Prior understanding of basic electrical circuit concepts by first year engineering students

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Abstract: There is a broad diversity of educational background of students entering Level 7 programmes in engineering. As a result, students' reasoning regarding basic electrical concepts often differs from accepted explanations. This contribution reports, analyses and reflects on the results of a multiple-choice diagnostic test to assess student understanding of such concepts (developed by Engelhardt and Beichner (2004) for high school and college students), taken by three cohorts of first year, Level 7, engineering students at Dublin Institute of Technology during the 2008-9 academic year.

1. Introduction

The author has had responsibility for instruction, at various times since 2004, in direct current resistive electrical circuits in a number of modules in the first year of three-year, Level 7, degree programmes at Dublin Institute of Technology. The Level 7 programmes are the DT009/DT016 programme in Electrical Engineering, the DT006 programme in Mechanical Engineering and the DT003 programme in Manutronics Automation. The author has noticed a broad diversity of educational background of students entering these programmes since he began instructing on them. To quantify this, the author asked students in the 2008-9 academic year about their previous educational background. Of the 85 students who replied, 84 had attended secondary school in Ireland; 81 had sat the Junior Certificate examination in Science, with 35 students sitting Physics or Physics and Chemistry in the Leaving Certificate, 17 of which sat the Higher Level paper in either of these subjects.

Many aspects of direct current resistive electrical circuits are introduced to students in the junior certificate cycle of second level education. For example, the Junior Certificate Science Syllabus (NCCA, 2003), advises, amongst other skills, that students on completion of the subject should be able to "set up a simple electric circuit, use appropriate instruments to measure current, potential difference (voltage) and resistance, and establish the relationship between them"; "demonstrate simple series and parallel circuits containing a switch and two bulbs"; "define and give the units for work, energy and power, state the relationship between work and power, and perform simple calculations based on this relationship". These areas are covered well in popular second level books and workbooks (Henly and Quirke (2003a), (2003b)). These skills are further developed should students study Physics or (much more rarely) Physics and Chemistry to Leaving Certificate level.

However, many students struggle with the topic, with students' reasoning about basic electrical concepts often differing from accepted explanations. The author has noticed in intensive teaching that this appears to apply to students of all previous educational backgrounds in the topic. This is an international phenomenon, with Engelhardt and Beichner (2004), for example, reporting that U.S. high school and university students have similar conceptual difficulties, even after instruction in the subject. These authors supply a 29 question multiple-choice test, which they label the Determining and Interpreting Resistive Electric Circuits

Concept Test (DIRECT), to tease out student misconceptions. They assess the test for validity and reliability, and provide detailed data regarding experiences of testing 1135 students, 681 at university level and 454 at high school level. The authors also provide a comprehensive reference list of other work which explores student understanding of DC resistive electric circuits.

The author decided, in the 2008-9 academic year, to apply this test to the cohort of students in the three Level 7 programmes mentioned above (n=83). The test duration is 30 minutes. The test was taken by the students at the start of instruction in the topic, and was not flagged in advance. This meant that the author could identify the nature of student misconceptions prior to material being covered in the lecture and laboratory environment, allowing the misconceptions to be addressed.

2. Analysis

The data from the test was analysed in a number of ways. Table 1 compares the mean value of correct answers for the Level 7 cohort to the student cohorts detailed by Engelhardt and Beichner (2004).

Table 1: Mean value of correct answers (in percentage) of student cohorts

Student cohort	%	n
Level 7, Year 1, 2008-9	39	83
High school students (USA)	41	454
University students (USA)	52	681

Disappointingly, on average, the Level 7 student cohort performed worse than US high school students and considerably worse than their peers in US universities. In other work, the author has determined that there is little difference between the mean performance of the three Level student cohorts. Table 2 shows a comparison of the mean value of the correct answers for the Level 7 cohorts who sat Physics for the Leaving Certificate (or equivalent), compared to the Level 7 cohorts whose relevant education concluded with Science at the Junior Certificate.

Table 2: Mean value of correct answers (in percentage) of student cohorts

Student cohort	%	n
Level 7, Year 1, 2008-9. Sat Physics in LC.	43	35
Level 7, Year 1, 2008-9. Did not sit Physics in LC.	36	48

Clearly, there is an unexpectedly low benefit, on average, for students in following the Physics Leaving Certificate curriculum. Further work has shown that those students who sat the higher-level paper in Physics in the Leaving Certificate had a mean score of 44%, and those students who sat the ordinary level paper had a mean score of 42%.

More detailed analysis on the answers to individual questions is available from the author. A summary of the difficulty level of the questions for the Level 7 student cohorts and the U.S. student cohorts is given in Figure 1. A glance at this figure tends to support the conclusion reached from the data in Table 1, but reveals some superior conceptual knowledge of Level 7 students compared to their U.S. counterparts. Thus, it is interesting to compare how well both cohorts of students performed on each of the instructional objectives that the test was designed to measure (Table 3). The data for the U.S. students (in brackets) is taken from Engelhardt and Beichner (2004).

Figure 1: Difficulty level of individual questions

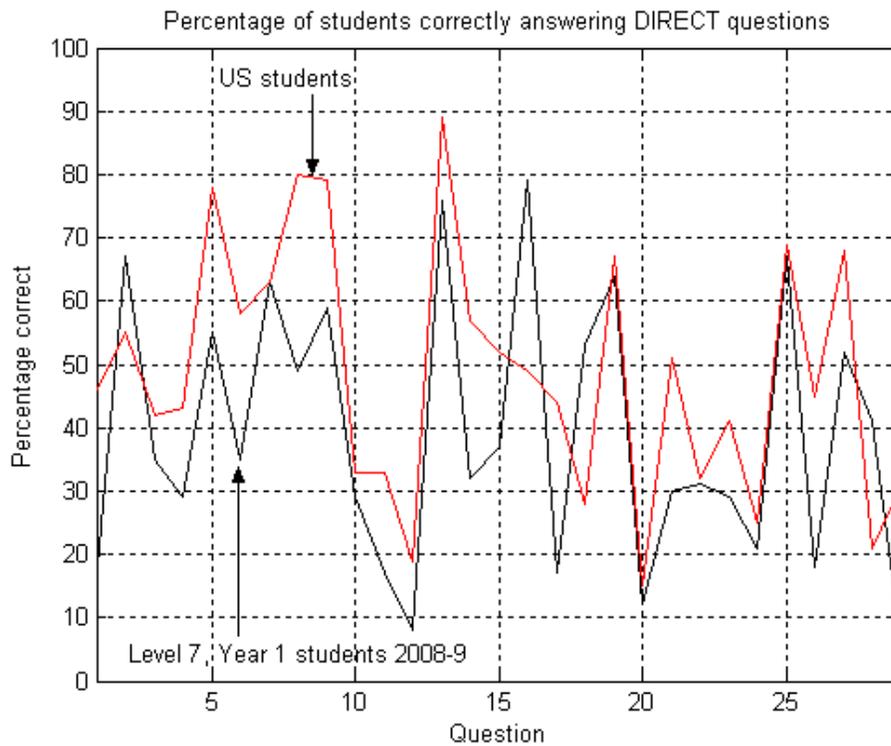


Table 3: Objectives for DIRECT and results

Objective	Question Numbers	Mean % correct
Physical aspects of DC electric circuits (objectives 1-5)		47 (56)
1. Identify and explain a short circuit	10, 19, 27	48 (56)
2. Understand the functional two-endedness of circuit elements	9, 18	56 (54)
3. Identify a complete circuit (objectives 1 to 3 combined)	27	52 (68)
4. Apply the concept of resistance	5, 14, 23	39 (59)
5. Interpret pictures and diagrams of a variety of circuits	4, 13, 22	45 (55)
Energy (objectives 6-7)		35 (42)
6. Apply the concept of power to a variety of circuits	2, 12	38 (37)
7. Apply a conceptual understanding of conservation of energy	3, 21	33 (47)
Current (objectives 8-9)		24 (44)
8. Understand and apply conservation of current	8, 17	33 (62)
9. Explain the microscopic aspects of current flow	1, 11, 20	16 (31)
Potential difference (voltage) (objectives 10-11)		50 (46)
10. Current is influenced by potential difference and resistance	7, 16, 25	72 (60)
11. Apply the concept of potential difference to a variety of circuits	6, 15, 24, 28, 29	28 (37)

Many of the objectives listed in Table 3 are compatible with the desired learning outcomes of the Junior Certificate Science programme, in particular. It is clear that the Level 7 students have, on average, a superior grasp of the concept of potential difference than their U.S. counterparts, but have an inferior grasp of the concepts of energy, current and the physical aspects of DC electric circuits. In particular, the concept of current causes difficulties for Level 7 students.

In the 2008-9 academic year, following this analysis, the author attempted to emphasise conceptual issues with one Level 7 student cohort and asked the students to redo the test, without notice been given, approximately 10 weeks into the lecture programme. However, only 13 of the cohort of 33 students took the test, and thus conclusions are difficult to draw from the data gathered. For what it is worth, there is an increase of 5% in the mean value of correct answers (from 40% to 45%).

3. Conclusions and further work

The author describes experiences of using the Determining and Interpreting Resistive Electric Circuits Concept Test to evaluate and analyse the level of conceptual knowledge of a number of cohorts of Level 7, Year 1 students. The author agrees with the conclusion of Engelhardt and Beichner (2004), that the test has potential “in evaluating curriculum or instructional methods as well as providing insight into students conceptual understanding of DC circuit phenomena”. Further work will concentrate on evaluating the misconceptions and difficulties determined by the test, and explicitly addressing these problems in the learning environment. The work reported in this paper has been restricted to a particular engineering student cohort but could be applied more widely to Irish students studying basic electricity in science and engineering programmes at second level and third level.

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