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Surveying First-Year Students Prior Conceptual Understanding of Direct Current Resistive Electric Circuits: an Update

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Surveying prior conceptual understanding of direct current resistive electric circuits of first year students in electrical engineering: an update

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Abstract. There is an increasing diversity of educational background of students entering Level 7 and Level 8 programmes in engineering in Irish third level education. Student reasoning about basic electricity concepts often differs from accepted explanations. The paper 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 U.S. high school and college students) taken by four cohorts of students, on the same DIT Level 7 engineering programme, from 2008-12 (n=106) and two cohorts of students, on the same DIT Level 8 engineering programme, from 2010-12 (n=64). This paper updates a previous contribution (O'Dwyer, 2009) which described the application of the test to two cohorts of Level 7 students in the 2008-9 academic year.

BACKGROUND

The author has had responsibility for instruction, at various times since 2004, of direct current resistive electrical circuits in modules in the first year of the three-year, Level 7, DT009 programme in electrical engineering, and the four-year, Level 8, DT021/DT081 programme in electrical/computer engineering, at Dublin Institute of Technology (DIT). Many aspects of direct current resistive electrical circuits are introduced to students in the early 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 (e.g. Henly and Quirke 2003a, 2003b). These skills are further developed should students study Physics or (more rarely) Physics and Chemistry to Leaving Certificate level. Of the Level 7 students who replied to a survey conducted by the author from 2008-11 (n=80), 45% of students sat a subject in which direct current resistive electric circuits were treated in detail (typically Physics or Physics and Chemistry in the Leaving Certificate); 77% of Level 8 students who replied to a survey from 2009-11 (n=56) had done likewise.

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; a sample of questions from the test is provided in the appendix. 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 author applied this test to four cohorts of students, on the same DIT Level 7 engineering programme, from 2008-12 (n=106), and two cohorts of students, on the same DIT Level 8 engineering programme, from 2010-12 (n=64). 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.

ANALYSIS

The data from the test was analysed in a number of ways. Table 1 compares the mean value of correct answers for the DIT student cohorts to a student cohort detailed by Engelhardt and Beichner (2004). The US high school students had completed relevant learning prior to taking the test.

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

Student cohort	%	n
DIT, Level 7, Year 1, 2008-12	42	106
DIT, Level 8, Year 1, 2010-12	42	64
High school students (USA)	41	454

Clearly, the performance of all student cohorts is approximately the same. Interestingly, there is no difference between the mean performance of Level 7 and Level 8 student cohorts, even though, for example, of the students who took Physics or Physics and Chemistry in the Leaving Certificate, a much greater percentage of Level 8 students (89%; n=28) than Level 7 students (47%; n=57) completed the higher level course. Other work performed by the author has shown that there is no statistically significant relationship between an individual's results on the DIRECT test and associated Leaving Certificate Physics or Physics and Chemistry grades (when converted to CAO point scores). Clearly, there is an unexpectedly low benefit, on average, for student understanding of concepts in electricity after students complete the Physics or Physics and Chemistry Leaving Certificate curriculum.

On the other hand, there is a highly statistically significant, weakly positive correlation between the performance in the DIRECT test and, respectively:
- Semester 1 examination performance in the Electrical Principles subject, for the Level 7 cohort of students, from 2008-12 (n=92, $p<0.001$, $r=0.36$).
- Terminal examination performance in the Electrical Principles subject, for the Level 7 cohort of students, from 2008-11 (n=66, $p<0.001$, $r=0.46$).

However, there is no statistically significant relationship between performance in the DIRECT test and, respectively:
- Semester 1 examination performance in the Electrical Systems subject, for the Level 8 cohort of students, from 2010-12 (n=54, $p>0.05$, $r = 0.00$).
- Terminal examination performance in the Electrical Systems subject, for the Level 8 cohort of students, from 2010-11 (n=29, $p>0.05$, $r = -0.08$), though this sample size is small.

More work is required to determine the reason for the differences in the experiences of Level 7 and Level 8 students summarised above. Based on this data, the DIRECT

test does not reliably predict students who may be in danger of failing their Year 1 examinations in the relevant subject; such a predictive capability would be useful as it would allow targeting of learning resources to these students in particular.

More detailed analysis on the answers to individual questions is available from the author. Table 2 shows how well the Level 7 (n=27) and Level 8 (n=39) cohorts of students, in the 2010-11 academic year, performed on each of the instructional objectives that the test was designed to measure; data for Level 7 students are in brackets.

Many of the objectives listed in Table 2 are compatible with the desired learning outcomes of the Junior Certificate Science programme, in particular (NCCA, 2003). It is clear that the concept of current, in particular, causes difficulties for students.

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

Objective	Question	%
Physical aspects of DC electric circuits (objectives 1-5)		**49 (40)**
1. Identify and explain a short circuit	10, 19, 27	45 (48)
2. Understand the functional two-endedness of circuit elements	9, 18	54 (44)
3. Identify a complete circuit	27	48 (44)
4. Apply the concept of resistance	5, 14, 23	41 (36)
5. Interpret pictures and diagrams of a variety of circuits	4, 13, 22	59 (45)
Energy (objectives 6-7)		**53 (50)**
6. Apply the concept of power to a variety of circuits	2, 12	52 (62)
7. Apply a conceptual understanding of conservation of energy	3, 21	54 (38)
Current (objectives 8-9)		**21 (23)**
8. Understand and apply conservation of current	8, 17	32 (44)
9. Explain the microscopic aspects of current flow	1, 11, 20	13 (9)
Potential difference (voltage) (objectives 10-11)		**42 (36)**
10. Current is influenced by potential difference and resistance	7, 16, 25	77 (60)
11. Apply the concept of potential difference to a variety of circuits	6, 15, 24, 26, 28, 29	25 (37)

CONCLUSIONS

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 basic electricity ideas of a number of cohorts of first year Level 7 and Level 8 engineering 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 d.c. circuit phenomena". Identifying the misconceptions and difficulties determined by the test allows explicit addressing of these problems in the learning environment. The work reported in this paper has been restricted to particular engineering student cohorts but could be applied more widely to Irish students studying basic electricity in science and engineering programmes in second level and third level education.

References

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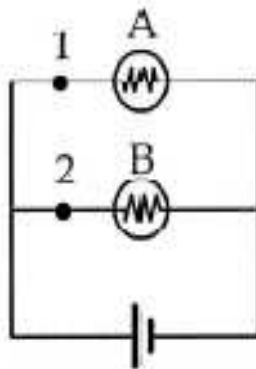
APPENDIX: SAMPLE OF QUESTIONS FROM THE DIRECT TEST

Q14. How does the resistance between the endpoints change when the switch is closed ?
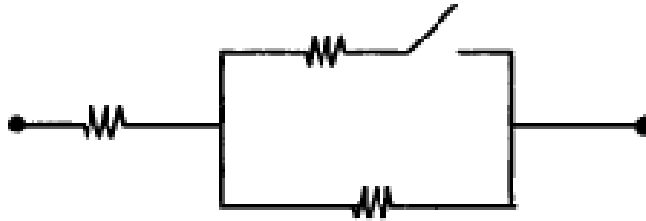
(a) Increases   (b) Decreases   (c) Stays the same

Q19. What happens to the brightness of bulbs A and B if a wire is connected between points 1 and 2 ?

(a) Increases   (b) Decreases   (c) Stays the same

(d) A becomes brighter than B   (e) Neither bulb will light

Q11. Why do the lights in your home come on almost instantaneously ?

(a) Charges are already in the wire. When the circuit is completed, there is a rapid re-arrangement of surface charges in the circuit.

(b) Charges store energy. When the circuit is completed, the energy is released.

(c) Charges in the wire travel very fast.

(d) The circuits in a home are wired in parallel. Thus, a current is already flowing.