The Conceptual Understanding Of Basic Electricity Concepts By Junior Engineering Students: An Update

Aidan O'DWYER

Technological University Dublin, Ireland, aidan.odwyer@tudublin.ie

THE UNDERSTANDING OF BASIC ELECTRICITY CONCEPTS BY FIRST YEAR ENGINEERING STUDENTS: AN UPDATE (RESEARCH-PRACTICE)

A. O'Dwyer [1]
School of Electrical and Electronic Engineering,
TU Dublin, Dublin, Ireland

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ABSTRACT

The paper reports, analyses and reflects on the results of a multiple-choice diagnostic test to assess student understanding of basic electricity concepts (developed for U.S. high school and college students [1]) taken by nine cohorts of first year engineering students (n=1286) at the authors university, from 2014 to date. The diagnostic test was taken prior to instruction by all student cohorts, and post-instruction by some student cohorts. This paper updates a previous contribution by the author which described the application of the test to seven cohorts of junior engineering students (n=203) from 2008 to 2013. The manner in which this work has influenced instructional methods is outlined.

1 INTRODUCTION

The author has had responsibility for instruction of direct current resistive electrical circuit concepts, over two decades, to cohorts of first year students enrolled on a four year engineering undergraduate programme. Many aspects of direct current resistive electrical circuits are introduced to students in the early cycle of second level education in Ireland, where the author is based. For example, the Junior Certificate Science Syllabus [2], covering the first three years of second level education in the subject in Ireland, 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

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[1] A.O'Dwyer, *aidan.odwyer@TUDublin.ie*

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. [3], [4]). These skills are further developed should students study Physics at the Leaving Certificate (the terminal Irish second level examination).

However, in the author's experience, 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 reference [1], 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) Version 1.0, 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. Subsequently, an updated test is proposed [5] (Version 1.1), discussing the authors experiences of testing 692 students, 441 at university level and 251 at high school level. Both tests take 30 minutes to complete. A sample of questions from Version 1.1 of the test is provided in the appendix.

Versions 1.0 and 1.1 of the DIRECT test have been subsequently applied, in pre-test, post-test and delayed post-test mode, with various cohorts of students in second and third level education; space permits mention of only some such examples. At second level, for example, DIRECT Version 1.1, in pre-test and post-test mode, was administered to students in the U.S.A. [6] and Cyprus [7]. At university level, for example, DIRECT Version 1.1, in pre-test and post-test mode, was administered to students in Turkey [8], the U.S.A. [9], and South Africa [10], and was administered, in pre-test, post-test and 11-week delayed post-test mode, to students in Turkey [11].

2 METHODOLOGY

The author requested nine cohorts of students, from 2014 to date, to complete DIRECT Version 1.1 before instruction. These students are enrolled in a common first year of an engineering program, and take the electrical circuits subject in Semester 1. The test was used to identify the nature of student misconceptions prior to material being covered in the lecture and laboratory environment, allowing misconceptions to be addressed. When the opportunity presented itself, the author requested students complete DIRECT Version 1.1 as a post-test immediately after instruction, and/or as a delayed post-test after instruction (at the start of Semester 2). This approach, similar to that applied in [11], allowed an evaluation of whether conceptual understanding of d.c. resistive electric circuits, as measured by the test, improved after instruction, and whether any improvement was sustained.

3   RESULTS

The data from the DIRECT 1.1 pre-test was analysed in two ways.

Table 1 shows the mean percentage test score by the student cohort over nine academic years, with n = number of students who sat the test, and N = number of students who sat the summative assessment in the subject at the end of the semester. Altogether, 1286/1466 or 88% of students sat the DIRECT 1.1 pre-test. Clearly, the pre-test scores for the cohorts of students are broadly similar; it should be noted that, in this multiple-choice test, a mean score of 20% would be expected if students chose the answers to the questions at random. It is clear that, on average, students have poor knowledge of electrical concepts, as measured by this test, as they start their engineering studies. This is despite all students having prior learning in this area at the Junior Certificate level (or equivalent); in addition, though the data is incomplete, it appears that approximately half of the student cohort may have studied Physics at the Leaving Certificate level, or equivalent (in 2019-20, for example, 71 of the 143 students did so). On a positive note, from the data available, a gain in mean post-test and delayed post-test scores is recorded, and is consistent, for the available data, over the period examined. This gain may be linked to the emphasis placed by the author on conceptual understanding in his teaching of the subject over this period. Similar improvements are recorded by Baser and Durmus [11] in their reporting of their use of enquiry learning techniques in the teaching of a d.c. electric circuits course to a cohort of Turkish pre-service elementary school teachers.

Table 1. Mean value of correct answers of some student cohorts

Student cohort	N	Pre-test	Post-test	Delayed post-test
2014-15	165	29 (n=144)	47 (n=109)	*Not done*
2015-16	151	30 (n=146)	49 (n=93)	49 (n=131)
2016-17	196	29 (n=159)	*Not done*	44 (n=164)
2017-18	159	27 (n=118)	*Not done*	45 (n=129)
2018-19	151	29 (n=118)	*Not done*	49 (n=132)
2019-20	143	31 (n=130)	*Not done*	49 (n=129)
2020-21	160	26 (n=162)	*Not done*	*Not done*
2021-22	169	30 (n=169)	*Not done*	*Not done*
2022-23	172	24 (n=140)	*Not done*	*Not done*

Tables 2a to 2d shows how well cohorts of students performed on each of the four instructional objectives that the test was designed to measure, with 'pre' and 'post' referring to data in pre-test mode, and delayed post-test mode (where available), respectively.

Firstly, twelve questions test understanding of the physical aspects of d.c. electric circuits, asking students to identify and explain a short circuit, test understanding of the functional two-endedness of circuit elements, identify a complete circuit, apply the concept of resistance, and interpret pictures and diagrams from a variety of circuits.

Secondly, four questions test understanding of energy, asking students to apply the concept of power to a variety of circuits, and apply a conceptual understanding of the conservation of energy idea.

Thirdly, five questions test understanding of current, asking students to understand and apply the conservation of current idea, and explain the microscopic aspects of current flow.

Finally, eight questions test understanding of potential difference, asking students to apply the concept of potential difference to a variety of circuits, and to assess how current is influenced by potential difference and resistance.

An example of a question from each of these instructional objectives is given in the appendix.

Table 2a: Mean value of correct answers (in percentage): physical aspects of d.c. circuits

	2014-5	2015-6	2016-7	2017-8	2018-9	2019-0	2020-1	2021-2	2022-3
Pre	38	38	35	35	37	40	29	37	30
Post		68	55	64	66	68			

Table 2b: Mean value of correct answers (in percentage): energy

	2014-5	2015-6	2016-7	2017-8	2018-9	2019-0	2020-1	2021-2	2022-3
Pre	22	22	24	20	20	22	16	24	19
Post		34	38	31	42	38			

Table 2c: Mean value of correct answers (in percentage): current

	2014-5	2015-6	2016-7	2017-8	2018-9	2019-0	2020-1	2021-2	2022-3
Pre	20	23	21	20	23	22	32	24	16
Post		32	34	29	36	34			

Table 2d: Mean value of correct answers (in percentage): potential difference

	2014-5	2015-6	2016-7	2017-8	2018-9	2019-0	2020-1	2021-2	2022-3
Pre	28	29	29	25	27	30	13	28	22
Post		42	36	38	37	39			

Tables 2a-2d reveal consistency in the results from year to year (except in 2020-2021, perhaps because the test had to be done on-line during the COVID-19 pandemic), and consistency between pre-test and post-test results (where available). Clearly, students are most comfortable, both before and after instruction, with an understanding of the physical aspects of d.c. electric circuits. More detailed analysis of the answers to individual questions are available from the author, and will be discussed in the conference presentation.

Previous work done by the author with a colleague [12], with the 2014-15 student cohort, shows a statistically significant correlation ($p < 0.05$) between student spatial ability and the conceptual understanding of the physical aspects of d.c. electric circuits as measured by the DIRECT test, with no statistically significant correlation between spatial ability and the other three instructional objectives of the DIRECT test. This work

remains relevant, as engineering graduates tend to have good spatial ability (for example, it has been shown that the majority of Science, Technology, Engineering and Mathematics (STEM) graduates in the USA (n = 400 000) had good spatial skills at age 13 [13]).

Overall, further work remains to be done in enhancing student conceptual understanding, particularly in the instructional objectives where improvement is most required. The author is addressing this in the classroom by concentrating on student learning of fundamental concepts using audience response systems to encourage collaborative learning, with colleagues in the laboratory using enquiry based learning for some activities. In addition, the use of problem based learning has been incorporated in other modules.

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APPENDIX

Instructional objective 1: Understanding of the physical aspects of d.c. electric circuits - sample question

13) Which schematic diagram best represents the realistic circuit shown below?

(A) Circuit 1
(B) Circuit 2
(C) Circuit 3
(D) Circuit 4
(E) None of the above

Circuit 1

Circuit 2
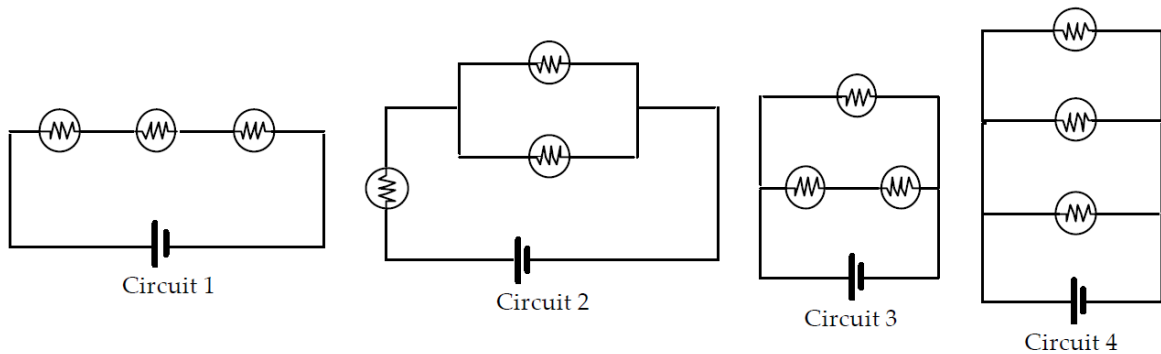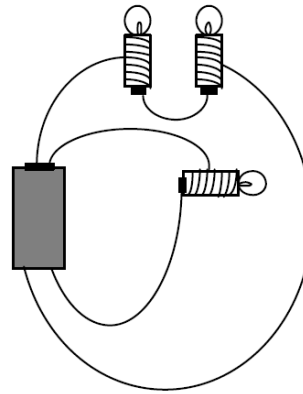
Circuit 3

Circuit 4

Instructional objective 2: Understanding of energy - sample question

2) How does the power delivered to resistor A change when resistor B is added to the circuit? The power delivered to resistor A _____.

(A) Quadruples (4 times)
(B) Doubles
(C) Stays the same
(D) Reduces by half
(E) Reduces by one quarter (1/4)

Before

After
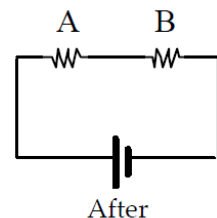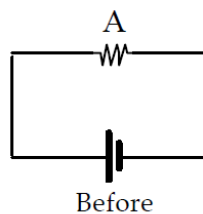
Instructional objective 3: Understanding of current - sample question
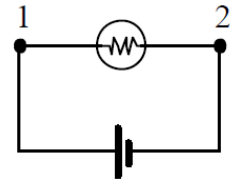
8) Compare the current at point 1 with the current at point 2. Which point has the LARGER current?

(A) Point 1

(B) Point 2

(C) Neither, they are the same. Current travels in one direction around the circuit.

(D) Neither, they are the same. Currents travel in two directions around the circuit.

Instructional objective 4: Understanding of potential difference - sample question

29) What happens to the brightness of bulbs A and B when the switch is closed?

(A) A stays the same, B dims
(B) A brighter, B dims
(C) A and B increase
(D) A and B decrease
(E) A and B remain the same