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Two-tier multiple-choice questions as a means of increasing discrimination: case-study of a basic electric circuits course

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ABSTRACT: One of the widely used tools for summative assessment in engineering education is the multiple-choice test. A two-tier multiple-choice question, in which the first item is a fact-based question and the second item is a reasoning-based question, permits higher-order thinking skills to be evaluated. The study described in this article characterised the discrimination level of two-tier multiple-choice questions in the final examination of the course, *Electric Circuit Theory*, intended for sophomore electrical engineering students. Six hundred and thirty-two students from the Technion - Israel Institute of Technology, Haifa, Israel, participated in the study. According to the findings, the discrimination level of two-tier multiple-choice questions is good and higher (with large effect size) than that of their one-tier counterparts.

Keywords: Two-tier multiple-choice questions, discrimination, electric circuit theory

INTRODUCTION

The final stage in teaching is summative assessment, which has the purpose of examining to what degree the learning goals have been attained [1]. One of the widely used instruments for summative evaluation is the multiple-choice test. This tool is particularly useful in courses with a large number of participants, such as engineering introductory courses. However, the critics of the multiple-choice test claim, inter alia, that it only examines lower-order thinking skills [2].

A possible solution for this is the use of two-tier multiple-choice questions (hereinafter, two-tier questions). In a two-tier question, the first item is a fact-based question requiring the student to remember a fact or to apply a rule to a given situation. The second item is a reasoning-based question requiring the student to provide the reason for the answer that was given to the first item, and necessitates higher-order thinking [3][4].

Similarly to questions in a standard multiple-choice test, several answers are provided for each of the two items, where one answer is correct and the others are distractors. Two-tier questions are employed in various disciplines, such as physics [5][6], chemistry [7][8] and biology [9][10].

One of the important characteristics of a test question, including a multiple-choice test question, is its discrimination level. A question with good discrimination is a question that students doing well on the test tend to answer correctly. For such a question on a multiple-choice test, the value of the point biserial correlation coefficient, measuring the correlation between the score for the question and the score for the test, fulfils the requirement of $r > 0.3$ [11]. The closer the value of r to one, the higher is the discrimination.

Recently, an attempt was made to characterise the discrimination of two-tier questions in electrical engineering. This characterisation was done for questions focusing on elementary direct and alternating current circuits, which were included in a test of non-electrical engineering major students. It was found that in most cases the discrimination level of two-tier questions was higher than that of their one-tier counterparts that did not contain the reasoning component [12].

The study described in this article characterised the discrimination level of two-tier questions in the final examination of the course, *Electric Circuit Theory*, which is intended for sophomore electrical engineering students. As opposed to Timmermann and Kautz [12], the two-tier questions covered a variety of topics, e.g. resistive circuits, digital circuits, frequency domain analysis and time domain transients. Additionally, the current study used a reference (control) group alongside the experimental group, which reinforced the validity of its findings.

The article is organised as follows: first the *Electric Circuit Theory* course is reviewed, followed by the research goal and methodology; finally, the analysis of the findings, and conclusions.

THE COURSE, *ELECTRIC CIRCUIT THEORY*

Electric Circuit Theory is a mandatory course for sophomore electrical engineering students at the Technion - Israel Institute of Technology. The course, which has been described extensively by Gero et al [13][14], has the purpose of providing the students with knowledge and skills in resistive circuit analysis, time domain transients, frequency domain analysis, capacitive and inductive coupling, digital circuits and operational amplifier-based circuits. Such knowledge and skills are aimed at serving the students in further courses in general, and particularly in those focusing on electronic devices and on analogue and digital circuits.

The course provides four credit points and extends over 13 weeks, with three hours of lectures and two hours of tutorials every week. The teaching method in all of these sessions is front facing. The course grade is determined on the basis of a final examination (76%) and home exercises submitted throughout the semester (24%). The course is based mainly on the textbook, Foundations of Analog and Digital Electronic Circuits [15].

RESEARCH GOAL AND METHODOLOGY

The aim of the study was to characterise the discrimination level of two-tier questions and compare it to that of the one-tier counterparts.

Six hundred and thirty-two students who took the course, *Electric Circuit Theory*, between 2017 and 2019 participated in the study. Of these students, 362 comprised the experimental group. This group attended the winter 2018/2019 course, in which the final examination was a multiple-choice test (one correct answer and four distractors). The test consisted of five two-tier questions alongside 12 one-tier questions. The one-tier questions focused on applying a rule or principle to a given circuit, through calculation. The two-tier questions required reasoning, in addition to the calculation. A two-tier question was scored as correct only if both items were correct. Each of the 17 questions was worth the same number of points.

The remaining 270 students comprised the reference or control group. This group attended the winter 2017/2018 course, in which the final examination was a multiple-choice test (one correct answer and four distractors). The test was comprised of 20 one-tier questions covering the application of a rule or principle to a given circuit, through calculation. All of the questions were assigned the same number of points.

Both groups were taught the same curriculum by the same experienced course faculty members. The characteristics of the students in both groups were similar. The two final examinations were written by the same course faculty members, and were validated by two engineering education experts. Each of the tests lasted three hours, and the students were permitted to use a calculator and a formula sheet that was attached to the test form. The students were informed in advance of the test structure.

Each of the five two-tier questions (winter 2018/2019) focused on a similar circuit to one that had been covered by a particular one-tier question (winter 2017/2018), and was of a similar level of difficulty. It should be noted that these one-tier questions were selected, so as to represent a wide variety of topics covered on the course. Additionally, the discrimination level (point biserial correlation coefficient r) of each one-tier question selected was good ($r > 0.300$).

This fact ensured that the one-tier questions selected were not problematic in the first place. Table 1 shows the topic and the discrimination level of each of the one-tier questions (reference group) that served as the basis for the two-tier questions (experimental group). An example of a one-tier question and a two-tier question is provided in Figure 1 and Figure 2, respectively.

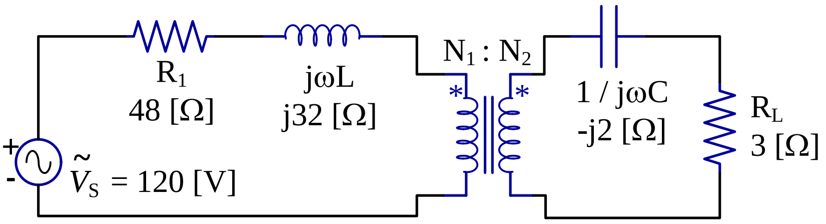
Table 1: One-tier questions (reference group) - topic and discrimination level.

No.	Topic	r_{1T*}
1	Resistive circuits	0.349
2	Digital circuits	0.376
3	Time domain transients	0.393
4	Frequency domain analysis	0.324
5	Inductive coupling	0.380

*Discrimination *r* one-tier

On the first stage of the analysis, the reference group was ignored and the focus was on the experimental group only, as was the case outlined by Timmermann and Kautz [12]. The authors compared the discrimination level (point biserial correlation coefficient) of a two-tier question to the discrimination level of the first item of that same question. In other words, first they took into account both parts of the two-tier question (calculation and reasoning), and then they considered the first component only (calculation) and treated it as a quasi one-tier question. In the second stage of the analysis, they compared the discrimination level of a two-tier question (experimental group) to the discrimination level of its one-tier counterpart (reference group).

In the circuit described below, an ideal transformer is used in order to transfer maximum output power to the load resistor marked as R_L.



The input voltage source is: $v_S(t) = 120 \cdot \cos(\omega t)$ [V].
The resistors' values are provided, as well as the impedance of the reactive components at the angular frequency at which the source operates.

What is the turns ratio required for maximum power transfer to the load?

A. $N_1: N_2 = 4$
B. $N_2: N_1 = 4$
C. $N_1: N_2 = 1$
D. $N_1: N_2 = 16$
E. $N_2: N_1 = 16$

Figure 1: One-tier question (reference group - question 5).

FINDINGS

Table 2 displays - for the experimental group - the discrimination level of two-tier questions and the discrimination level of the first item of the same questions (quasi one-tier question).

Table 2: Two-tier questions and quasi one-tier questions (experimental group) - discrimination level.

No.	r_{2T*}	r_{q1T**}
1	0.471	0.303
2	0.592	0.465
3	0.520	0.359
4	0.636	0.497
5	0.435	0.178

*discrimination *r* two-tier
**discrimination *r* quasi one-tier

The table shows that the discrimination level of each two-tier question is good ($r > 0.300$). It can also be seen that the discrimination level of each two-tier question is higher than that of the quasi one-tier question derived from it. The difference between the discrimination levels ($M = 0.170$; $SD = 0.051$) is characterised by a very large effect size ($d = 3.334$).

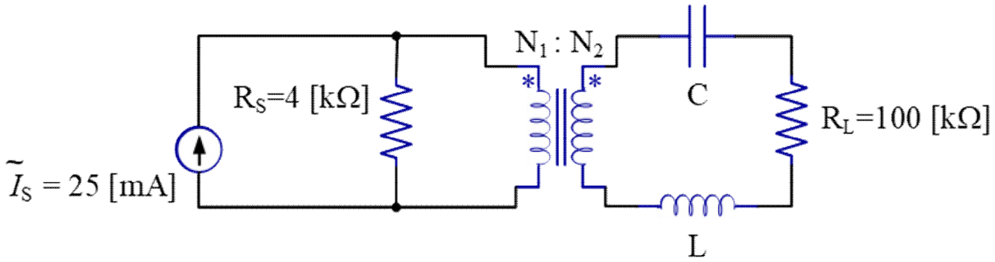
Table 3: Two-tier questions (experimental group) and one-tier questions (reference group) - discrimination level.

#	r_{2T}	r_{1T}
1	0.471	0.349
2	0.592	0.376
3	0.520	0.393
4	0.636	0.324
5	0.435	0.380

As it is possible that in answering the first item of the question, students were influenced by the answers provided on the reasoning item, the above difference could be biased. Therefore, in order to obtain a better estimation, Table 3 shows the comparison of the discrimination level of two-tier questions (experimental group) with the discrimination level of the one-tier counterparts (reference group).

It can be seen that also here, the discrimination level of each two-tier question is higher than that of the one-tier counterpart. The difference between the discrimination levels (M = 0.167; SD = 0.100) is characterised by a large effect size (d = 1.670) that is smaller as compared to the effect size obtained by the former method.

For the two following questions, consider the sinusoidal steady state circuit described below.



The values of the resistors are given.
The input current source is:
$i_S(t) = 25 \cdot \cos(\omega t)$ [mA],
where the angular frequency is $\omega = \frac{1}{\sqrt{LC}}$.
The ideal transformer has the purpose of transferring maximum output power to the load resistor R_L.

What is the turns ratio required for maximum power transfer to the load?

A. $N_1: N_2 = 1$
B. $N_2: N_1 = 5$
C. $N_1: N_2 = 5$
D. $N_1: N_2 = 25$
E. $N_2: N_1 = 25$

Which of the following statements is correct in relation to the circuit?

A. In going from one side of the transformer to the other, the power increases according to the turns ratio squared.
B. As the RLC series circuit on the load side is in resonance, transformation is unnecessary to transfer maximum power to the load.
C. As the circuit is supplied by a current source, transformation is unnecessary to transfer maximum power to the load.
D. As the RLC series circuit on the load side is in resonance, the condition for transferring maximum power to the load is the same as that obtained for a DC source connected in place of $i_S(t)$.
E. The condition for transferring maximum power to the load is the same for a practical current source and a practical voltage source equivalent to each other.

Figure 2: Two-tier question (experimental group - question 5).

DISCUSSION AND CONCLUSIONS

Based on the findings, the discrimination level of two-tier questions is good, regardless of the topic of the question. Furthermore, the discrimination level of each two-tier question is higher than that of the one-tier counterpart, and the difference between them is characterised by a large effect size.

This result matches in part the findings reported by Timmermann and Kautz, according to which in most cases the discrimination of two-tier questions was higher than that of the one-tier counterparts that did not contain the reasoning component [12]. However, it should be kept in mind that Timmermann and Kautz did not use a reference group and their findings could be biased [12].

This study has two main limitations:

1. the number of two-tier questions was relatively small;

2. some of the students in the experimental group could have been exposed to the relevant one-tier questions on the test given to the reference group (which was conducted a year earlier).

As to the first limitation, it should be noted that it is very difficult to create a test that is only comprised of two-tier questions. To reduce the possible learning effect mentioned as the second limitation, each two-tier question was based on a similar circuit and was of a similar degree of difficulty as its one-tier counterpart, but was not identical.

The advantage of two-tier questions over one-tier questions is added, as far as improving the discrimination level, to other advantages mentioned in the literature (and not addressed in this article), such as the possibility of identifying and monitoring students' misconceptions [16][17]. The authors believe these advantages justify applying two-tier questions in engineering education, in spite of the considerable effort involved in creating them.

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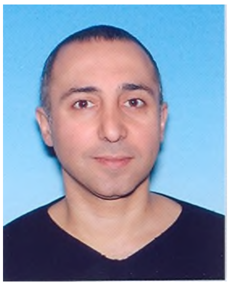
BIOGRAPHIES

Aharon Gero holds a BA in physics (*Summa Cum Laude*), a BSc in electrical engineering (*Cum Laude*), an MSc in electrical engineering, and a PhD in theoretical physics, all from the Technion - Israel Institute of Technology, Haifa, Israel. In addition, he has an MBA (*Cum Laude*) from the University of Haifa, Israel. Dr Gero is an Assistant Professor in the Department of Education in Technology and Science at the Technion, where he heads the Electrical Engineering Education Research Group. Before joining the Technion, he was an instructor at the Israeli Air-Force Flight Academy. Dr Gero's research focuses on electrical engineering education and interdisciplinary education that combines physics with electronics, at both the high school and higher education levels. Dr Gero has received the Israeli Air-Force Flight Academy Award for Outstanding Instructor twice and the Technion's Award for Excellence in Teaching 12 times. In 2006, he received the Israeli Air-Force Commander's Award for Excellence, and in 2016 was awarded the Yanai Prize for Excellence in Academic Education.



Yinnon Stav (Satuby) received a BSc degree in electrical engineering and a BA degree in physics both in 1995, and an MSc degree in electrical engineering in 1997, all from the Technion - Israel Institute of Technology. His research topic focused on the dynamics of semiconductor lasers. From 1997 until 2003, he worked on fibre optic telecommunication and DWDM (dense wavelength division multiplexing) technologies at ECI Telecom Ltd, and later on at Multilink Technology Corporation. In 2007, he received a PhD degree in electrical engineering from the Technion. His research dealt with plasmonics-based nano-photonics. From 2007 until 2012, he was with the Finisar Corporation, developing high speed photoreceivers and working on advanced fibre-optic modulation formats. At present Dr Stav is with the Engineering School at Ruppin Academic Center, Israel, where he heads the Electrical Engineering and Electronics Programme. He also serves as an adjunct faculty member in the Andrew and Erna Viterbi Faculty of Electrical Engineering, Technion.

Irit Wertheim holds a BSc and a PhD in architecture and town planning from the Technion - Israel Institute of Technology. Her research on *A Morphological Approach to Geometry* was conducted in co-operation with the Department of Education in Technology and Science and the Department of Architecture and Town Planning. Dr Wertheim is the assessment and evaluation consultant in the Centre for Promotion of Learning and Teaching at the Technion. Before joining the Technion, she served as the Head of Education in MadaTech - Israel National Museum of Science, Technology and Space.

Ariel Epstein received a BA degree in computer science in 2000 from the Open University of Israel, Ra’anana, both a BA degree in physics and a BSc degree in electrical engineering in 2003, and a PhD degree in electrical engineering in 2013, all from the Technion - Israel Institute of Technology, Haifa, Israel. From 2013 to 2016, he was a Lyon Sachs Postdoctoral Fellow with the Department of Electrical and Computer Engineering, University of Toronto, Toronto, ON, Canada. At present, he is an Assistant Professor with the Andrew and Erna Viterbi Faculty of Electrical Engineering, Technion, where he leads the Modern Electromagnetic Theory and Applications (META) Research Group. His current research interests include utilisation of electromagnetic theory, with emphasis on analytical techniques, for the development of novel metasurface and metagrating-based antennas and microwave devices; and investigation of new physical effects. Dr Epstein was a recipient of the Young Scientist Best Paper Award in the URSI Commission B International Symposium on Electromagnetic Theory (EMTS2013), held in Hiroshima, Japan, in 2013. Since 2018, he has served as an associate editor for the IEEE Transactions on Antennas and Propagation.