

# Summative Assessment Based on Two-Tier Multiple-Choice Questions: Item Discrimination and Engineering Students' and Teachers' Attitudes\*

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Summative assessment is carried out at the end of the teaching process, and should be objective, reliable and valid. The standard multiple-choice test is a common summative assessment tool in engineering education. However, one of the main arguments against this test is that it examines only lower-order thinking skills. A possible solution is the use of two-tier multiple-choice questions. The research described in the paper characterized summative assessment, based on two-tier multiple-choice questions, in a course on electric circuits. The study compared the discrimination level of two-tier multiple-choice questions to that of their one-tier counterparts, and explored students' and teachers' attitudes toward incorporating the former into the final examination. The study, which used quantitative and qualitative instruments, involved 575 sophomore electrical engineering students at the Technion – Israel Institute of Technology. The findings indicate that the discrimination level of two-tier multiple-choice questions is significantly higher than that of their one-tier counterparts. Both students and faculty believe that two-tier multiple-choice questions can examine higher-order thinking skills and that their discrimination level should be higher than that of one-tier questions. They further agree that two-tier multiple-choice questions are not applicable to every subject.

**Keywords:** assessment; two-tier multiple-choice questions; item discrimination; attitudes; electrical engineering

## 1. Introduction

Through evaluation processes, it is possible to estimate the extent to which learning objectives have been achieved. It is common to distinguish between two main types of assessment, formative and summative [1]. Formative assessment is conducted throughout the course as an integral part of teaching. It provides the student with feedback that includes strengths and weaknesses, allowing him/her to improve later on [2]. Summative assessment is performed at the end of the teaching process, and should be objective, reliable and valid [3, 4].

One of the common tools for summative assessment, especially in multi-participant courses, is the multiple-choice test [5]. In most cases, a multiple-choice test involves a relatively large number of questions, where each question has several answers, one of which is correct, and the others are distractors [6]. This instrument has many advantages, e.g., covering all (or almost all) the topics studied (validity), number of items examining the same content area (reliability), lack of bias in marking (objectivity), fast automated marking and the ability to perform statistical analysis of examinees' answers (item analysis) [7].

One of the main arguments against the multiple-choice test is that it examines only lower-order thinking skills [8]. Lower-order thinking is often

characterized by retrieving information from memory or applying knowledge in familiar situations. In contrast, higher-order thinking requires more complex cognitive activities [9]. In line with this distinction, in the well-known Bloom's taxonomy (cognitive domain), knowledge and application, for example, are lower-order thinking skills, while analysis and evaluation are higher-order thinking skills [10].

A possible solution to weakness mentioned above is the use of two-tier multiple-choice questions (hereinafter, TTMC questions). In a TTMC question, the first item is a fact-based question, which requires remembering a fact or applying a rule in a given situation. The second item is a reasoning-based question, which requires justification for the answer given in the first item and necessitates higher-order thinking [11, 12]. Similar to questions in a standard multiple-choice test (comprised of one-tier questions), each of the two items has several answers, with one answer correct and the rest are distractors.

Studies conducted in a variety of fields of knowledge, such as mathematics [13, 14], physics [15, 16], chemistry [17, 18], biology [19, 20] and engineering [21], show that TTMC questions allow to evaluate higher-order thinking skills. In addition, they permit to characterize students' misconceptions [22, 23]. Thus, for example, high-school students'

misconceptions in probability [24] and photosynthesis [25] were identified, based on an analysis of their answers to TTMC questions.

The present study did not focus on characterizing misconceptions through TTMC questions – a topic that has received, as stated above, a comprehensive attention in literature. Instead, it dealt with analyzing the discrimination level of TTMC questions and exploring students' and teachers' attitudes toward incorporating TTMC questions into final examinations. These topics have so far received little research attention.

The discrimination level is one of the important characteristics of a multiple-choice test question [26]. A question with a good discrimination is a question that students doing well on the test tend to answer correctly. Recently, an attempt has been made to assess the discrimination level of TTMC questions in electrical engineering. This evaluation was performed for questions that focused on simple 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 TTMC questions was higher than that of one-tier questions that did not include the reasoning component [27]. Another study characterized the discrimination level of a few TTMC questions included in the final examination of a basic course for electrical engineering students. The study, which was based on descriptive statistics, found that the discrimination level of TTMC questions is good and even higher than that of their one-tier counterparts [28].

The present research considerably expanded previous studies by analyzing the discrimination level of TTMC questions dealing with a wide range of topics taught in a basic course on electric circuits. In addition, the study characterized students' and teachers' attitudes toward incorporating TTMC questions into the final examination. To the best of our knowledge, such characterization was performed here for the first time.

The paper is structured as follows. First, key metrics are defined for calculating discrimination levels. Next, the basic course on electric circuits is introduced. Then, the research questions are formulated, and the methodology is described. Finally, the main findings and conclusions are presented.

## 2. Discrimination Level

As stated above, one of the important characteristics of a multiple-choice test question is its discrimination level [26]. A question with a good discrimination is a question that students doing well on the test tend to answer correctly. There are two leading metrics for estimating the discrimi-

nation level, i.e., the discrimination index and the point biserial correlation coefficient.

For the purpose of calculating the discrimination index of a given question (the score on which is dichotomous), the examinees should be divided into two groups, Group T in which those who received a relatively high score on the test (top 27%) and Group B in which those who received a relatively low score on the test (bottom 27%). If we denote in  $t$  the number of examinees from Group T getting the question correct, in  $b$  the number of examinees from Group B getting the question correct, and in  $n$  the number of 27% of all students, then discrimination index of the question is [29]:

$$d = \frac{t - b}{n} \quad (1)$$

It is worth mentioning that some use a value of 25% or 33% instead of the original value of 27% [30]. The index ranges from  $-1$  to  $+1$ , and the higher it is – the better the discrimination level. It is important to note that there is no agreed standard regarding the minimum value of the index that indicates an acceptable discrimination, and this value ranges from 0.2 to 0.4 [31].

The second metric, point biserial correlation coefficient, measures the correlation between the dichotomous question score and the test score [32] and is given below:

$$r = \frac{M_p - M_q}{s} \sqrt{pq} \quad (2)$$

$M_p$  is the mean test score of students who answered the question correctly,  $M_q$  is the mean test score of students who answered the question incorrectly,  $s$  is the standard deviation of all students' test scores,  $p$  is the fraction of students who answered the question correctly and  $q = 1 - p$  is the fraction of students who answered the question incorrectly. The correlation coefficient ranges from  $-1$  to  $+1$  and the higher it is – the better the discrimination level. A value of  $r > 0.2$  indicates a question with an acceptable discrimination level [29]. Since the correlation coefficient (2) is well defined and has a standard for an acceptable discrimination level, it was used in this study.

## 3. Electric Circuit Theory Course

“Electric Circuit Theory” is a compulsory course for sophomore electrical engineering students at the Technion – Israel Institute of Technology [33, 34]. The prerequisites are courses in mathematics (ordinary differential equations) and physics (electromagnetism). At the end of the course, the student should be able to analyze electric circuits, based on

**Table 1.** Electric Circuit Theory course – curriculum

Week	Topics
1	Lumped circuits, lumped circuit elements, Kirchhoff's laws
2	Resistive circuits, voltage and current sources (practical and controlled), nodal analysis technique
3	Nodal analysis technique (continued), network theorems
4	Nonlinear circuits, small signal linearization
5	Digital abstraction, digital circuits, reactive elements
6	Transient response (1st order circuits)
7	Transient response (2nd order circuits)
8	Power and energy considerations (1st and 2nd order circuits)
9	Sinusoidal steady state circuits, frequency domain analysis
10	Power and energy considerations (frequency domain), first order frequency filters, frequency response
11	Resonance
12	Capacitive and inductive coupling
13	Operational amplifiers, A/D and D/A convertors

his/her knowledge in mathematics, physics and engineering [35]. The course covers fundamental topics in electric circuit theory, e.g., lumped circuit analysis, transient response, frequency domain analysis, and nonlinear circuits. The knowledge and skills acquired should serve students in further courses in general, and particularly on those dealing with electronic devices and analog and digital circuits.

The course (4 credit points) lasts 13 weeks, with three weekly hours of lectures and two hours of tutorials. Attendance at lectures and tutorials is optional. The teaching method is front facing. The grade is determined on the basis of a final examination (76%) and homework exercises (24%). The course is based on the textbook, “Foundations of Analog and Digital Electronic Circuits” [36]. The curriculum is given in Table 1.

#### 4. Research Goal and Questions

The study aimed to characterize summative assessment, based on TTMC questions, in the Electric Circuit Theory course.

The following questions were formulated:

- Is there a difference between the discrimination level (point biserial correlation coefficient) of TTMC questions and that of their one-tier counterparts?
- What are students' attitudes toward incorporating TTMC questions into the final examination?
- What are teachers' attitudes toward incorporating TTMC questions into the final examination?

#### 5. Methodology

##### 5.1 Participants

The study involved 575 sophomore electrical engineering students (Technion – Israel Institute of

Technology) who recently attended the Electric Circuit Theory course. Three hundred and five students made up the experimental group and took the winter 2019/20 course. Their final examination was a multiple-choice test, in which the vast majority of questions were TTMC questions and the rest – one-tier questions. The remaining 270 students made up the reference group. This group took the winter 2017/18 course, and their final examination was a standard multiple-choice test (comprised of one-tier questions). The characteristics of the students in both groups were similar and their age was ranging from 19 to 25.

In addition, the course faculty participated in the study. The same teaching team taught both groups and was comprised of a lecturer and three teaching assistants. The lecturer held a PhD in electrical engineering and had a 10-year teaching experience. The teaching assistants were graduate students in electrical engineering with a significant teaching experience. All of them (lecturer and assistants) were considered as good teachers.

##### 5.2 Procedure

The study combined quantitative and qualitative tools with the purpose of increasing the findings' trustworthiness and allowing the presentation of various aspects of the phenomenon being investigated [37]. Both groups (experimental and reference) were taught the same curriculum (Table 1) by the same faculty. Students were informed at the beginning of the course of the final test structure. After taking the final examination, 124 students from the experimental group gave their consent to answer an anonymous open-ended questionnaire. The questionnaire focused on students' attitudes toward incorporating TTMC questions into the final examination. In addition, semi-structured interviews were held with the course faculty. The

**Table 2.** Participants and instruments

Participants	Group	N	Tool
Students	Experimental	305	Final examination
		124	Questionnaire
	Reference	270	Final examination
Course faculty		4	Interview

interviews, which lasted about 20 minutes each, dealt with teachers' attitudes toward the integration of TTMC questions in the final test. The interviews were recorded and transcribed in full. Table 2 summarizes the details about the participants and the instruments used.

The quantitative data were statistically analyzed. The qualitative data underwent conventional content analysis in which coding categories were derived directly from the data [38]. Only findings obtained at least three times were taken into account.

### 5.3 Tools

#### 5.3.1 Final Examination

The final examination of both groups was written by the course faculty and validated by two experts in engineering education. Each examination was a multiple-choice test (one correct answer and four distractors). The distractors reflected common mistakes students had made over the years. Each test lasted three hours and the students were allowed to use a calculator and a formula sheet attached to the test form.

The experimental group's examination included ten TTMC questions alongside four one-tier questions, with all 14 questions being of equal value. The one-tier questions focused on the application of a rule or principle in a given circuit, through calculation. The TTMC questions required reasoning, based on the circuit analysis, in addition to the calculation. A TTMC question was scored as correct only if both items were correct. The reference group's examination was comprised of 20 one-tier questions dealing with the application of a rule or principle in a given circuit, through calculation. All 20 questions were of equal value.

Each of the ten TTMC questions (winter 2019/20) focused on a circuit similar to one that had been covered by a particular one-tier question (winter 2017/18) and was of a similar level of difficulty. It is important to emphasize that the one-tier questions were chosen so as to represent a wide range of topics covered on the course. In addition, the discrimination level of each one-tier question selected was acceptable ( $r > 0.200$ ). This fact ensured that the one-tier questions selected were not problematic in

**Table 3.** One-tier multiple-choice questions (reference group) – topic and discrimination level

#	Topic	<i>r</i> (one-tier)
1	Resistive circuits	0.349
2	Nodal analysis technique	0.327
3	Nonlinear circuits	0.312
4	Digital circuits	0.376
5	Transient response (1st order circuits)	0.393
6	Transient response (2nd order circuits)	0.396
7	Frequency domain analysis	0.324
8	Frequency domain analysis	0.246
9	Inductive coupling	0.372
10	Operational amplifiers	0.385

the first place. Table 3 presents the topic and discrimination level of the one-tier questions (reference group) that formed the basis of the TTMC questions (experimental group). An example of a TTMC question and its one-tier counterpart is given in Appendix A.

#### 5.3.2 Questionnaire

The anonymous open-ended questionnaire included ten questions and focused on students' attitudes toward incorporating TTMC questions into the final examination. The questions were validated by two engineering education experts. A sample of the questions is given in Appendix B.

#### 5.3.3 Interview

The semi-structured interview was comprised of seven questions and dealt with teachers' attitudes toward integrating TTMC questions in the final test. The questions were validated by two engineering education experts. A sample of the questions is given in Appendix C.

## 6. Findings

First, we compare the discrimination level of TTMC questions to that of their one-tier counterparts. Next, we present students' and teachers' attitudes toward incorporating the former into the final examination.

### 6.1 Discrimination Level

Overall, students' performances on the test were similar in both groups ( $M = 66.56$ ,  $s = 19.75$ , experimental group;  $M = 65.81$ ,  $s = 17.55$ , reference group, where  $M$  ranging from 0 to 100). As for item discrimination, Table 4 shows the discrimination level of TTMC questions (experimental group) and that of their one-tier counterparts (reference group).

It is evident that in all cases the discrimination

**Table 4.** Two-tier multiple-choice questions (experimental group) and one-tier multiple-choice questions (reference group) – discrimination level

#	1	2	3	4	5	6	7	8	9	10
<i>r</i> (two-tier)	0.432	0.455	0.535	0.393	0.553	0.544	0.479	0.559	0.368	0.562
<i>r</i> (one-tier)	0.349	0.327	0.312	0.376	0.393	0.396	0.324	0.246	0.372	0.385

level of TTMC questions is acceptable ( $r > 0.200$ ). Moreover, it turns out that in 9 of the 10 questions, the discrimination level of TTMC questions is higher than that of their one-tier counterparts. Fisher  $z$ -transformation indicates a significant difference ( $z = 2.06$ ,  $p < 0.05$ ) between the mean discrimination level of TTMC questions ( $M = 0.491$ ) and that of one-tier questions ( $M = 0.349$ ).

## 6.2 Students' Attitudes

Content analysis of students' answers to the open-ended questionnaire yielded the following categories: learning during the course, studying for the final examination, and advantages and disadvantages in incorporating TTMC questions into the final test.

### 6.2.1 Learning During the Course

The vast majority of students argue that knowing in advance about the integration of TTMC questions in the final examination does not affect attendance at lectures (88%)

"I make sure to attend the lectures regardless of the exam structure."

attendance at tutorials (84%)

"I attended all the tutorials, but it was regardless of the specific type of the questions [on the exam]."

and time spent solving homework problems (77%)

"Homework helps me to understand the material, so one way or another [regardless of the exam structure] I attach great importance to it."

### 6.2.2 Studying for the Final Examination

Most students (64%) claim that knowing in advance about the incorporation of TTMC questions into the final examination did not affect the time spent studying for the examination:

"I would not say that it [structure of the exam] affected the time spent studying."

However, more than a third of them (39%) think that the integration of these questions led to an in-depth study of theory while studying for the final examination:

"[While studying for the final exam,] I spent a lot of time on understanding theory rather than on technical issues. And that's because of the two-tier questions."

### 6.2.3 Advantages

Most students (60%) believe that TTMC questions can examine higher-order thinking skills:

"It [a TTMC question] requires analyzing the electric circuit before solving equations. . . One must view the big picture."

About one-sixth of the students (17%) claim that TTMC questions better reflect the gap between strong and weak students than one-tier questions:

"For strong students, the benefit [of incorporating TTMC questions into exams] is reduced time pressure when solving the test. This is because they understand how the reasoning item is related to the previous item [calculation]."

### 6.2.4 Disadvantages

About one-sixth of the students (17%) believe that TTMC questions are not applicable to every subject:

"There are simple [TTMC] questions in which the reasoning item is less relevant."

Tables 5–6 summarize students' attitudes toward incorporating TTMC questions into the final examination.

## 6.3 Teachers' Attitudes

Content analysis of teachers' answers in the interviews identified advantages and disadvantages in integrating TTMC questions in the final examination.

### 6.3.1 Advantages

The course faculty believe that TTMC questions can examine higher-order thinking skills:

"This [TTMC question] makes it possible to test students' ability to analyze [circuits] beyond mere technical calculations."

Additionally, teachers think that TTMC questions sharpen the difference between strong and weak students:

"This [reasoning item] makes it easier for strong students. . . They solved the first part [calculation] correctly and it's clear to them what they did and why they did. . . Therefore, unlike weak students, they don't spend much time on the second part [reasoning], easily earn points for the entire question and save time."

**Table 5.** Students' attitudes toward incorporating two-tier multiple-choice questions into the final examination (learning during the course and studying for the final examination)

Category	Subcategory	Frequency (%)	Example	Interpretation
Learning during the course	Attendance at lectures	88	"In my opinion, the exam structure does not affect attendance at lectures."	Knowing in advance about the integration of TTMC questions in the final examination does not affect attendance at lectures
	Attendance at tutorials	84	"Anyway, I would attend all tutorials."	Knowing in advance about the integration of TTMC questions in the final examination does not affect attendance at tutorials
	Time spent solving homework problems	77	"Anyway, I would spend the same amount of time solving homework problems."	Knowing in advance about the incorporation of TTMC questions into the final examination does not affect the time spent solving homework problems
Studying for the final examination	Time spent studying for the examination	64	"I spent a lot of time [studying for the exam] regardless of the exam structure."	Knowing in advance about the incorporation of TTMC questions into the final examination led to an in-depth study of theory while studying for the final examination
	In-depth study of theory	39	"While studying for the final exam, I put an emphasis on theory."	

**Table 6.** Students' attitudes toward incorporating two-tier multiple-choice questions into the final examination (advantages and disadvantages)

Category	Subcategory	Frequency (%)	Example	Interpretation
Advantages	Examining higher-order thinking skills	60	"TTMC questions require analysis and deep understanding of the principles your solution is based on."	TTMC questions can examine higher-order thinking skills
	Higher discrimination level	17	"TTMC questions save time for strong students, because answering the reasoning item is relatively easy for them."	TTMC questions better reflect the gap between strong and weak students
Disadvantages	Limited applicability	17	"I think there is no need to use TTMC questions everywhere."	TTMC questions are not applicable to every subject

### 6.3.2 Disadvantages

The course faculty believe that TTMC questions are not applicable to every subject, especially not to simple ones:

"Not all topics are suitable [for TTMC questions], especially not the easy topics, in which calculation is definitely enough and reasoning is trivial."

In addition, the teaching staff argue that there is a difficulty in creating good TTMC questions, in which the reasoning item is significant enough, but at the same time does not provide clues that may assist students in solving the first item (calculation):

"It's difficult to write a good reasoning question. . . On the one hand, the question should examine students' considerations, but on the other hand, it should not provide students with clues for the first part [calculation]. . . It's indeed a very delicate task."

### 6.3.3 Optimal Mixture

Given the pros and cons associated with TTMC questions, the course faculty claim that the optimal final examination should be based mostly (but not entirely) on TTMC questions:

"[For me, in the exam] the vast majority of the questions should be TTMC questions, but not 100%, because there are topics that require very simple technical calculations, so reasoning is trivial."

Table 7 summarizes teachers' attitudes toward incorporating TTMC questions into the final examination.

## 7. Discussion

The study analyzed the discrimination level of TTMC questions on electric circuits and compared it to that of their one-tier counterparts. In addition,

**Table 7.** Teachers' attitudes toward incorporating two-tier multiple-choice questions into the final examination

Category	Subcategory	Example	Interpretation
Advantages	Examining higher-order thinking skills	"The exam [based on TTMC questions] not only tests knowledge, but far beyond that."	TTMC questions can examine higher-order thinking skills
	Higher discrimination level	"For weak students, it [reasoning item] makes it difficult, because even if they answered the first part [calculation] correctly, then in the second part [reasoning] they'll encounter difficulty and have to devote time or guess correctly to earn points for the entire question."	TTMC questions sharpen the difference between strong and weak students
Disadvantages	Limited applicability	"There're topics that are too simple, so there's no point in writing TTMC questions."	TTMC questions are not applicable to every subject
	Difficulty in writing good TTMC questions	"It's really difficult to write the second question [reasoning]... One should make sure that all the answers [correct answer and distractors] are meaningful, yet not providing clues to the first part [calculation]."	There is a difficulty in creating good TTMC questions
Optimal mixture		"Given their benefits, most questions [in the exam] should be TTMC questions, but not all. . . Not all topics are relevant."	The optimal final examination should be based mostly (but not entirely) on TTMC questions

the study explored students' and teachers' attitudes toward the incorporation of TTMC questions into the final examination.

The qualitative findings indicate that both students and course faculty believe that integrating TTMC questions in the final examination makes it possible to test higher-order thinking skills. This finding is in line with results obtained in previous studies [39], which point to this salient advantage of TTMC questions in a variety of fields, such as science [15], engineering [21] and business administration [12]. It is worth noting that students claim that TTMC questions "require analyzing the electric circuit" and, therefore, "one must view the big picture". Seeing the big picture is a prominent feature of systems thinking [40], which is considered as higher-order thinking [41], and the ability to perform functional analysis is a key skill of the so-called systems thinker [42].

Additionally, students and teachers think that the discrimination level of TTMC questions should be higher than that of their one-tier counterparts, because the second item in TTMC questions (reasoning) is related to the first item (calculation). Therefore, for strong students, answering the second item is relatively easy, and it allows them to earn points for the entire question and also to devote time to other questions. Weak students, on the other hand, spend relatively much time answering the reasoning item and have difficulty in earning points for the entire question, even if they answered the first item correctly.

According to the quantitative results, in the vast majority of cases (90%) the discrimination level of TTMC questions is indeed higher than that of their one-tier counterparts. The results also indicate a

significant gap, in favor of the former, between the discrimination level of the two types of questions. These findings are consistent with those described in [27, 28], according to which in most cases, the discrimination of TTMC questions is higher than that of one-tier questions. However, it should be noted that the authors of [27] did not use a reference group and their findings might be biased.

Students and course faculty also agree that TTMC questions are not applicable to every subject, especially if it is too simple. The teaching staff identifies another disadvantage (or challenge), according to which there is a considerable difficulty in writing good TTMC questions. In such questions, the reasoning item is significant enough (thus testing higher-order thinking and increasing the discrimination level), but, at the same time, not providing weak students with clues to solving the calculation item (thus reducing the discrimination level). Hence, according to the course faculty, an optimal final examination should be based mostly (but not entirely) on TTMC questions. This position is largely consistent with that described in [27], based on the authors' experience.

It is interesting to note that most students argue that knowing in advance about the incorporation of TTMC questions into the final examination did not affect learning during the course in terms of attendance at lectures and tutorials and solving homework problems. However, more than a third of the students claim that the integration of these questions led to an in-depth study of theory while studying for the final examination.

The study has a limitation, according to which some of the students in the experimental group could have been exposed to relevant one-tier ques-

tions on the test given to the reference group (which took place two years earlier). To minimize the possible learning effect, the TTMC questions were based on a similar electric circuit and were at the similar level of difficulty as their one-tier counterparts, but were not identical.

The contribution of the present study is in analyzing the discrimination level of TTMC questions dealing with a wide range of topics covered in a basic course on electric circuits. In addition, the study characterized students' and teachers' attitudes toward the integration of TTMC questions in the final examination. To the best of our knowledge, such characterization was performed here for the first time.

Given the benefits of TTMC questions, we recommend including such questions in final examinations in multi-participant engineering courses. In further research, we intend to explore the use of

TTMC questions in other engineering courses, at both the high-school and higher education levels.

## 8. Conclusions

The study characterized summative assessment, based on TTMC questions, in a sophomore course on electric circuits. Both students and faculty believe that TTMC questions can examine higher-order thinking skills and that their discrimination level should be higher than that of one-tier questions. They further agree that TTMC questions are not applicable to every subject. According to the findings, the discrimination level of TTMC questions is indeed significantly higher than that of their one-tier counterparts.

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## Appendix A: Final Examination

The final examination, mentioned in Section 5.3.1, was a multiple-choice test (one correct answer and four distractors). Below are a one-tier question (reference group) and its two-tier counterpart (experimental group). Both questions deal with frequency domain analysis (Question 7 in Tables 3–4).

### A1. One-Tier Question

Consider the sinusoidal steady state circuit shown in Fig. A1.

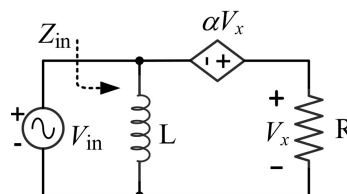


Fig. A1. Sinusoidal steady state circuit (one-tier question).

The input voltage source is:

$$v_{in}(t) = V_{in} \cos(\omega t)$$

and  $L, R, \alpha$  are provided.

What is the input impedance,  $Z_{in}$ ?

- A.  $Z_{in} = \frac{j\omega L \cdot R(1-\alpha)}{j\omega L + R(1-\alpha)}$
- B.  $Z_{in} = \frac{j\omega L \cdot R(1+\alpha)}{j\omega L + R(1+\alpha)}$
- C.  $Z_{in} = \frac{j\omega L \cdot R}{j\omega L + R}$
- D.  $Z_{in} = j\omega L$
- E.  $Z_{in} = 0$

#### A2. Two-Tier Question

For the following two items, consider the sinusoidal steady state circuit shown in Fig. A2.

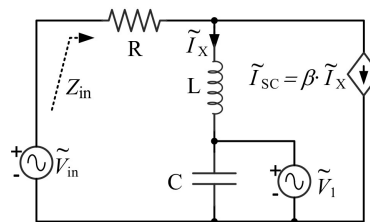


Fig. A2. Sinusoidal steady state circuit (two-tier question).

The voltage sources are:

$$v_{in}(t) = V_{in} \cos(\omega t)$$

$$v_1(t) = V_1 \cos(\omega t)$$

and  $L, R, C, \beta$  are provided.

1. What is the Thévenin-equivalent input impedance,  $Z_{in}$ ?

- A.  $Z_{in} = R + j\omega L$
- B.  $Z_{in} = R$
- C.  $Z_{in} = R + \frac{j\omega L}{(1+\beta)}$
- D.  $Z_{in} = R + j \frac{(\omega L - \frac{1}{\omega C})}{(1+\beta)}$
- E.  $Z_{in} = R + j \left( \omega L - \frac{1}{\omega C} \right)$

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

- A. The input impedance is obtained by turning off all sources.
- B. At resonance frequency,  $\omega_0 = 1/\sqrt{LC}$ , the input impedance is purely imaginary.
- C. According to the substitution theorem, the input impedance is not affected by the value of  $C$ .
- D. At resonance frequency,  $\omega_0 = 1/\sqrt{LC}$ , there is no current through the current source.
- E. The input impedance is not affected by the value of  $L$ , because the current source becomes a short circuit.

## Appendix B: Questionnaire

The open-ended questionnaire, mentioned in Section 5.3.2, included ten questions and focused on students' attitudes toward incorporating TTMC questions into the final examination. The following is a sample of the questions:

- What do you think about incorporating TTMC questions into the final examination? Explain.
- Did knowing in advance that the final examination would include TTMC questions affect how you studied during the semester? Explain.
- What are the benefits of incorporating TTMC questions into the final examination? Explain.
- What are the disadvantages in incorporating TTMC questions into the final examination? Explain.

## Appendix C: Interview

The semi-structured interview, mentioned in Section 5.3.3, was comprised of seven questions and dealt with teachers' attitudes toward incorporating TTMC questions into the final examination. The following is a sample of the questions:

- What do you think about incorporating TTMC questions into the final examination? Explain.
- What are the benefits of incorporating TTMC questions into the final examination? Explain.
- What are the disadvantages in incorporating TTMC questions into the final examination? Explain.
- What is the optimal mixture of one-tier and TTMC questions in the final examination? Explain.

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