Assessing Students' Practical Skills in Basic Electronic Laboratory based on Psychomotor Domain Model

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Abstract

In engineering education, laboratory experiments or practical works are integrated in the curriculum to prepare students for engineering experience and practice prior to their graduation. Laboratory experiments provide students with knowledge and practical skills and expose them to the relevant engineering field. This paper investigates the levels of practical skills acquired by students after conducting the laboratory experiments with reference to Psychomotor Domain Taxonomy. This is achieved by administering a laboratory practical test at the end of the semester. A Skill Assessment Form was used as a checklist in identifying the levels of students' practical skills. Four levels of students' practical skills in Basic Electronic Laboratory were identified. The results indicate that there are some variations in students' performance at each skill level.

Keywords: assessment, laboratory experiments, practical skills, psychomotor domain;

1. Introduction

Laboratory experiment is critical in the education for engineers; hence, the experiments are integrated in the engineering curriculum to prepare students for engineering experience and practice prior to their graduation (Feisel and Rosa, 2005; Al-Bahi, 2007; Krivikas and Krivikas, 2007). According to Schank *et al*. (1999), the most effective method to teach students to do something is by asking them to perform the task. Therefore, by conducting the laboratory experiments, students learn by practicing the skills that cannot be learned theoretically.

There are numerous rationales for the integration of laboratory experiments in a particular course. Numerous literature relate the integration of laboratory experiments with the theoretical and practical aspects of a course (Edward, 2002; Feisel and Rosa, 2005; Krivikas and Krivikas, 2007; Davies, 2008). Apart from that, when engaging in the laboratory experiments, students have the opportunity to develop and practice their practical skills and hands-on skills (Hunter, Mccosh and Wilkins, 2003; Krivikas and Krivikas, 2007; Watai, Brodersen and Brophy, 2007). They are also exposed to report writing and other generic skills such as team working and communication skills when performing the laboratory experiments (Edward, 2002; Krivikas and Krivikas, 2007). The other skill which students might improve is their technical skills (Mathew and Earnest, 2004). Thus, this paper will investigate these issues further by analyzing the students' practical skills abilities after conducting laboratory experiment in Basic Electronic Laboratory (BEL) for one semester. The assessment frequently employed and the psychomotor domain which relates to the conducts of experiments in BEL is discussed in the following section.

2. Assessment

Assessment is defined as a judgment about students' achievements which requires certain evidence (Alias, 2005; Harlen, 2007) such as students' knowledge, skills and abilities (Harlen, 2007). Many literatures have argued that written report is the most common assessment method in the laboratories (Zaghloul, 2001; Edward, 2002; Hunter, Mccosh and Wilkins, 2003; Mathew and Earnest, 2004; Pickford and Brown, 2006; Harris *et al*., 2007; Krivikas and Krivikas, 2007). However, the drawback of written reports is its failure to assess the practical skills demonstrated by

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students (Edward, 2002; Pickford and Brown, 2006). Another limitation of written reports is that it merely measures the product of learning, for example, students' ability to write the report (Davies, 2008). The assessment of laboratory reports is not comprehensive and does not accurately measure the students' ability in conducting the experiments, hence the practical skills acquired by students.

Other assessment methods for laboratory experiments include the use of logbook, notebook or lab diaries and oral presentation (Hunter, Mccosh and Wilkins, 2003; Harris *et al*., 2007). Practical skills test or practical skills assessment (Zaghloul, 2001; Harris *et al*., 2007) are also utilized in evaluating the students' performance in the laboratory. However, these tests are mainly employed to assess the students' ability to perform specific laboratory activities such as to operate laboratory equipment (Alinier and Alinier, 2005; Harris *et al*., 2007).

3. Psychomotor domain

Students' practical skills in the laboratory are associated with the psychomotor domain. This domain focuses on manual task that require the manipulation of objects and physical activities (Merrit, 2008). According to Zaghloul (2001) and Merrit (2008), human mind and body are link together while performing those activities.

Ferris and Aziz (2005) have introduced seven levels of psychomotor domain hierarchy related to laboratory experiment in engineering education (refer to Table 1). According to Kennedy, Hyland and Ryan (2006), this psychomotor domain model is specific for engineering students and could be used to assess the physical actions of engineers (Hoffmann, 2008).

Table 1. Psychomotor domain model

Level	Descriptions
1. Recognition of tools and materials	Ability to recognize the tools of the trade and the materials.
2. Handling of tools and materials	Ability to handle (pick, move and set down) the tools and materials and to handle objects without damage to either the object or other objects in its environment or hazard to any person.
3. Basic operation of tools	Ability to perform the elementary, specific detail tasks such as to hold the tool appropriately for use, to set the tool in action.
4. Competent operation of tools	Ability to fluently use the tools for performing a range of tasks of the kind for which the tools were designed.
5. Expert operation of tools	Ability to use tools rapidly, efficiently, effectively and safely to perform work tasks on a regular basis.
6. Planning of work operations	Ability to take a specification of a work output required and performs the necessary transformation of the description of the finished outcome into a sequence of tasks that need to be performed.
7. Evaluation of outputs and planning means for improvement	Ability to look at a finished output product and review that product for quality. Ability to identify particular deficiencies and the actions which could be taken to correct the faults or to prevent the faults through appropriate planning.

Source: Ferris and Aziz (2005)

Even though there are other psychomotor domain taxonomies such as the one proposed by Dave and Simpson (Kennedy, Hyland and Ryan, 2006), the psychomotor domain model (PDM) proposed by Ferris and Aziz (2005) is applied in this study. Each level in the PDM clearly describes the types of skills to be performed by students and can be easily mapped with the laboratory experiments demonstrated by the students in BEL.

The following discussion will investigate the practical skills acquired by students after conducting the laboratory experiments in BEL. The participants in this study were first-year students enrolled in Diploma in Electronic Engineering (DDE), College of Science and Technology (CST), Universiti Teknologi Malaysia. For details of the diploma program offered by CST and the associated laboratory course, please refer to Salim, Puteh and Daud (2009).

4. Electrical Laboratory I course

The Electrical Laboratory I course (DDE1711) is offered to students in the second semester of the DDE program. This laboratory course was designed to enhance students' knowledge and practical skills in using basic electronic components, operating basic electrical instruments such as power supplies as well as operating measuring instruments such as ammeter, voltmeter, multi-meter, oscilloscope and digital probe.

Students are required to complete nine experiments in this course (refer to Table 2). The table also illustrates that three experiments were conducted in the Analogue Laboratory; three experiments were conducted in the Instrumentation Laboratory whereas the remaining three experiments were conducted in the Digital Laboratory.

Table 2. The experiments for DDE1711

No. of Experiment	Topics	Name of Laboratory
1	Using Analogue Meters and Error Calculating.	Instrumentation Laboratory
2	Multi-meter and Voltage Control Oscillator	Instrumentation Laboratory
3	Oscilloscope and Function Generator	Instrumentation Laboratory
4	Series Circuits	Analogue Laboratory
5	Parallel and Series-Parallel Circuits	Analogue Laboratory
6	Capacitors	Analogue Laboratory
7	Fundamentals of logic gates and IC data sheets	Digital Laboratory
8	Implementation of Boolean Theorem	Digital Laboratory
9	Implementation of decoder in digital systems	Digital Laboratory

For the purpose of this paper, only the experiments conducted in the Instrumentation Laboratory and Analogue Laboratory will be discussed because the practical skills performed by the students in both laboratories are almost similar whereby students were required to operate basic electrical instruments. Furthermore, the types of instruments available in these two laboratories are almost similar. These laboratories are referred to as Basic Electronic Laboratory (BEL).

The experiments in BEL are conducted every week, commencing from week 3 of the semester. During the experiments, students work in pairs for three consecutive hours. In a normal practice, eight pairs of students will work on the same experiments simultaneously.

The laboratory session was supervised by a lecturer who was responsible to brief students on the experiments and to assess students' achievement. For each laboratory session, students were given a laboratory worksheet and a pre-formatted laboratory report. The former consists of the following:

1. Objectives of the experiment
2. List of experimental components and equipments
3. Experimental procedures which include the schematic diagram of the circuit

On the contrary, the pre-formatted laboratory report consists of pre-formatted tables for students to fill in the measured and the theoretical (calculated) values. The discussions and conclusion of the experiments were also required to be completed in the pre-formatted laboratory report. At the end of the laboratory session, each group was required to submit their pre-formatted laboratory report to the lecturer.

The current assessment method for the DDE1711 course is based on the laboratory report. The laboratory report alone is insufficient as it does not evaluate the students' ability in conducting the experiment and in operating the laboratory instruments. There were cases where students' experimental results were correct despite making mistakes in constructing their own circuit. After probing further, it was discovered that they adjusted their results in the laboratory report.

For the purpose of improving the current assessment method, the authors highly recommend that the laboratory practical test is implemented in DDE1711 course. The test was employed as one of the assessment components for the laboratory experiments and was implemented in Semester 2 of the 2009/2010 academic session. This had enabled the lecturers to identify the practical skills acquired by the students as well as their weaknesses in performing the experiments.

Other than the laboratory practical test, a Skill Assessment Form was developed by the authors and was used as a checklist for identifying students' practical skills while performing the laboratory practical test. In addition, a survey instrument known as Formative Assessment Form was also administered to thirty-five students in an attempt to gauge their perception on their own practical skills levels. However, for the purpose of this paper, only the results of the Skill Assessment Form will be further discussed.

5. Methodology

There are several levels of research methodology applied in this research. These are:

1. Identifying the practical skills
2. Designing laboratory practical test
3. Developing Skill Assessment Form

5.1. Identifying the practical skill

Laboratory worksheets in BEL were analyzed and reviewed. The common procedures and tasks for each laboratory worksheet were grouped according to the practical skills performed by students during the experiments. Next, the authors compared the practical skills that have been identified with the psychomotor domain model (PDM) listed in Table 1 in order to categorize the practical skills according the specified levels. Table 3 shows the identified practical skills and the mapping of the skills to the PDM.

Table 3. Practical skills in BEL mapped to PDM

	Tasks	Descriptions / Examples	Corresponding PDM Level
1.	Name and identify types of component	Name the resistor, diode, LED. Identify the different types of capacitors, i.e. ceramic and electrolytic.	Recognize (Level 1)
2.	Sketch/ identify the symbols of the components and instruments	Sketch the symbol of resistor, diode, LED. Identify the components and instruments from the schematic diagram.	Recognize (Level 1)
3.	Explain the function of components and instruments	Explain the function of resistor, diode or function generator.	Recognize (Level 1)
4.	Construct circuit	Construct series circuit on the project board.	Not Available
5.	Connect instruments	Connect power supply to the circuit. Connect oscilloscope to the circuit.	Basic Operation (Level 3)
6.	Set the instrument to the required value	Set the frequency of function generator.	Basic Operation (Level 3)
7.	Use the instrument to measure the required value	Set the function switch of a multi-meter to measure resistance, ac and dc voltages and dc current. Set the VOLT/DIV of the oscilloscope to the suitable range.	Basic Operation (Level 3)
8.	Record the reading of the measuring instruments	Record the indication of multi-meter. Record the waveform displayed by the oscilloscope	Not Available

Task 1 to task 3 in Table 3 could be easily mapped to PDM Level 1 (recognize). Similarly, tasks 5 to 7 could be easily mapped to Level 3 (basic operation) of the PDM. However, tasks 4 and 8 could not be matched to any level because these tasks do not fit into the descriptions of the PDM described in Table 1. Level 2 of the PDM (handling of tools and materials) could be incorporated into Level 3. This is because in order to operate an instrument, normally a person has to take and move the instrument whereas Hoffmann (2008) argued that the skills description for Level 2 is almost similar to Level 1. This justifies why Level 2 could be eliminated.

Level 4 (competent operation) and Level 5 (expert operation) of the PDM are not related to any of the practical skills in BEL because the practical skills in BEL only involve the use of basic instruments. Thus, it is difficult to differentiate between the basic, competent and expert operations of the basic measuring instruments. None of the tasks specified in the laboratory worksheets could be matched to Levels 6 and 7 of the PDM.

5.2. Designing laboratory practical test

A laboratory practical test was designed to determine the practical skills acquired by the students after conducting the laboratory experiments. This practical test was conducted at the end of the semester, when the students have completed all the experiments (i.e. in Week 15).

The laboratory practical test consisted of three different parts. The purpose of Part 1 was to identify the students' ability to recognize the basic components used during the laboratory experiments. Every student was given five components. They were asked to name the components, draw the symbol and determine the value of the components where applicable.

The focus of Part 2 was to test students' ability in constructing the series-parallel resistors circuit. Their ability to connect the multi-meter for measuring the current and voltage in the circuit and to record the multi-meter's indication was also investigated.

The purpose of Part 3 was to determine the students' ability to operate the oscilloscope and function generator. In this practical test, students were asked to set the amplitude and frequency of the function generator and adjust the control knobs of the oscilloscope for displaying the waveform. Lastly, their ability to measure and record the voltage displayed by the oscilloscope was also investigated.

The laboratory practical test was monitored by four lecturers with one lecturer to five students. These lecturers were responsible to grade the students' answers in the answer sheets and observe them performing the practical test. The lecturers completed the Skill Assessment Form while observing the students performing the practical test and also by referring to the students' answer sheets. The lecturers were also required to comment on the difficulties faced by the students while performing the practical test.

5.3. Developing Skill Assessment Form

In order to identify the practical skills acquired by the students, the authors have developed a Skill Assessment Form. This form was designed subsequent to the analysis of the laboratory worksheet and the design of the laboratory practical test. This form was used by the lecturers as a checklist in identifying the students' practical skills in performing the tasks specified in the practical test. Table 4 illustrates the Skill Assessment Form.

Table 4. Skill Assessment Form

Item	**Skill: Ability to recognize basic electronic components**		**Able**	**Not Able**
1.	Resistor	Symbol		
		Value (from code color)		
2.	Variable resistor	Symbol		
3.	Ceramic capacitor	Symbol		
4.	Electrolytic capacitor	Symbol		
5.	LED	Symbol and polarity		
Item	**Skill: Ability to construct circuit**		**Basic ***	**Competent ****
6.	Construct the circuit on the project board			
Item	**Skill: Ability to use (operate) the meters/ instruments**		**Basic***	**Competent****
7.	Connect multi-meter to the circuit			
8.	Connect oscilloscope to the circuit			
9.	Set function generator to the specified frequency			
10.	Set function generator to the specified amplitude			
11.	Calibrate the oscilloscope			
Item	**Skill: Ability to interpret the measurement**		**Basic ***	**Competent ****
12.	Record the measured voltage of the multi-meter according to the range selected			
13.	Record the waveform displayed on the oscilloscope according to the setting of VOLT/DIV			

* Basic - performing tasks with some difficulties

** Competent - performing tasks accurately without any assistance

The items in Table 4 were categorized into four different groups, according to the types of practical skills performed in the laboratory. The groups were arranged in the sequences of work performed by students during the experiments. Items 1 to 5 focused on the students' ability to recognize the symbol for basic electronic components. Students' ability to determine the values and the polarity of the components was also categorized under this category. Item 6 focused on the students' ability to construct the circuit whereas Items 7 to 11 tested the students' ability to operate the instruments which include connecting the instruments and calibrating them. Lastly, students' ability to interpret the measuring instrument's indication is described by items 12 and 13.

6. Results and Discussions

This section discusses the data obtained from the Skill Assessment Form which was analyzed using descriptive statistics for frequencies.

6.1. Recognition of components

Table 5 shows the results of laboratory practical test related to the students' ability to recognize the components that they have used during the experiments in BEL.

Table 5. Recognition of components

Item	Skill: Ability to recognize basic electronic components		Able (%)	Not Able (%)
1.	Resistor	Symbol	100	0
		Value (from color code)	89	11
2.	Variable resistor	Symbol	78	22
3.	Ceramic capacitor	Symbol	54	46
4.	Electrolytic capacitor	Symbol	51	49
5.	LED	Symbol and polarity	64	36

Table 5 indicates the five items which reflect the components in the laboratory experiment for DDE1711. The first item involves the resistor. Students learned the theory about resistors and analyzed resistors' circuits in the Electric Circuit course in the first semester. Besides, four out of six experiments conducted in BEL were related to resistors' circuit. This rationalizes why 100% of the students were able to sketch the symbol of resistor. The percentage of the students who could determine the value of resistors based on color code is slightly less (89%). This indicates that most of the students could remember the color code of the resistors.

The second item involves the recognition of variable resistor. The result of the laboratory practical test indicated that only 78% of the students were able to sketch the symbol of variable resistor. This was anticipated because the variable resistor was rarely applied in the laboratory experiment.

The capacitor was another item tested on the students. The percentages of students who could sketch the symbol of ceramic and electrolytic capacitors were slightly more than 50%. Several students sketched the symbol of ceramic capacitor with polarity and the symbol of electrolytic capacitor without polarity. These mistakes might be due to the fact that the focus of the lecturer was only on the analysis of capacitors' circuit.

The last component included in the Skill Assessment Form is LED. The result of the practical test indicated that only 64% of the students were able to sketch the symbol correctly. This was expected because only one experiment involved the LED.

6.2. Constructing the circuit

Table 6 shows the result of the Skill Assessment which address the students' ability to construct the circuit.

Table 6. Constructing the circuit

Item	Skill: Ability to construct circuit	Basic (%)	Competent (%)
1.	Construct the circuit on the project board	12	88

All experiments in DDE1711 course required the students to construct the circuit onto the project board. Referring to Table 6, a high percentage of students (88%) were able to construct the circuit without any assistance.

6.3. Operating the instrument

Table 7 illustrates the tasks related to students' ability to operate the instruments in the laboratory and the results of the practical test.

Table 7. Operating the instrument

Item	Skill: Ability to operate the meters and instruments	Basic (%)	Competent (%)
1.	Connect multi-meter to measure total current	57	43
2.	Connect multi-meter to measure branch current	85	15
3.	Connect oscilloscope to the circuit	57	43
4.	Set the frequency of function generator	23	77
5.	Set the amplitude function generator	63	37
6.	Calibrate the oscilloscope	51	49

The entire six laboratory experiments conducted in BEL requires the students to connect and operate the multi-meter. Only 43% of the students were able to connect the multi-meter for measuring total current in the circuit without any assistance. The percentage of the students who were able to connect the multi-meter for measuring branch current is even lower (15%). The lecturers reported that most of the students were unable to reconstruct the circuit and insert the multi-meter in series with the resistor. They either connected the multi-meter in parallel with the resistor or with the internal connection of the project board. Perhaps, these students did not have sufficient opportunity to perform the task on their own during the laboratory sessions as the experiment was conducted in groups.

The percentage of students who still need assistance to connect the oscilloscope for measuring the output waveform is 57%. This relatively high percentage might be due to the limited exposure in using the oscilloscope during the laboratory sessions where only two experiments in BEL required students to operate the oscilloscope.

The percentages of students who were able to set the frequency of function generator is higher (77%) compared to those who were able to set the amplitude (37%). A detailed analysis of the students' answer sheets indicated that students' inability to set the amplitude of function generator was related to their inability to interpret the waveform displayed by the oscilloscope.

6.4. Interpreting the measurement

Table 8 illustrates the results of the practical test that address the students' ability to interpret the multi-meter's indication as well as the waveform displayed by the oscilloscope.

Table 8. Interpreting the measurement

Item	Skill: Ability to interpret the measurement	Basic (%)	Competent (%)
1.	Record the measured dc voltage indicated by the multi-meter	63	37
2.	Record the waveform displayed on the oscilloscope according to the setting of VOLT/DIV	63	37

Only 37% of the students were competent in recording the voltage indicated by the multi-meter and the waveform displayed by the oscilloscope. According to the lecturers, there were students who recorded the measured value higher than the range of the analogue multi-meter that they have selected.

7. Conclusion

This paper has investigated the students' practical skills in the Basic Electronic Laboratory. The psychomotor domain model proposed by Ferris and Aziz (2005) was used to develop the Skill Assessment Form in categorizing the practical skills. Students' achievement was tested using the laboratory practical test, administered at the end of an academic semester. The practical skills studied in this research were related to the recognition of components and basic operation of the psychomotor domain model. In addition, students' ability in constructing the circuit and interpreting the instruments' indication were also examined.

The authors have categorized students' practical skills in Basic Electronic Laboratory into four levels namely ability to recognize basic electronic components (Level 1); ability to construct circuit (Level 2); ability to operate the instruments (Level 3) and ability to interpret the measurement (Level 4).

From the result of the study, it is highly recommended that the current assessment method which only relies on the laboratory report is revised. The new assessment method should specifically assess students' knowledge and practical skills with respect to laboratory experiments. Students' practical skills should be assessed by administering a laboratory practical test. A comprehensive assessment of students' performance in the laboratory is important in producing graduates who are able to integrate between the theory and practice of the electronic engineering courses as well as to perform the practical skills expected from them.

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