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An Instrument for Measuring the Learning Outcomes of Laboratory Work

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ABSTRACT

Outcome-based education emphasizes that course learning outcomes for every course in the program should be stated and made known to the students. However, the learning outcomes for laboratory work in the engineering curriculum are not widely discussed or not well defined. This study explores the most common learning objectives and outcomes of laboratory work in engineering education discussed in the literature. In general, the outcomes can be divided into three domains of learning: cognitive, psychomotor and affective. This paper proposes an instrument for measuring students' perceptions on the outcomes of laboratory work on their cognitive, psychomotor and affective domains. The survey questionnaire was constructed based on the identified laboratory course learning objectives and outcomes, and the authors' experience as engineering educators. The items were categorized into three constructs: cognitive, psychomotor and affective. A reliability test using SPSS indicated the following Cronbach's alpha coefficients: 0.901 (cognitive), 0.853 (psychomotor) and 0.774 (affective). These reliability indices show that the instrument has good reliability, and thus has the potential to be used in different settings.

Keywords: *laboratory work, learning outcomes, knowledge, practical skills, attitude.*

INTRODUCTION

Outcome-based education emphasizes that the course learning outcomes for every course in the program should be stated and announced to the students. According to Felder and Brent (2003), course learning outcomes represent the statement of observable students' action that specify the knowledge, skills and attitudes that should be acquired by students after completing a course. These learning outcomes should be observable and measurable (Besterfield-Sacre *et al*., 2000; Felder and Brent, 2003) and should be clearly written using action verbs that describe specific tasks (Houghton, 2004; Biggs and Tang, 2007) such as calculate, derive and explain (Felder and Brent, 2003).

Laboratory learning objectives and outcomes would help the educators to assess students' knowledge, skills and attitudes in laboratory work. However, learning outcomes for laboratory work in the engineering curriculum are not widely discussed or not well defined (Feisel and Peterson, 2002a; Mathew and Earnest, 2004; Feisel and Rosa, 2005). Feisel and Peterson (2002b) also argued that the learning outcomes of laboratory work are vague. Thus, this study explores the most common learning objectives and outcomes of laboratory work in engineering education discussed in the literature.

Based on the identified learning objectives and outcomes, and the authors' experience as engineering educators, survey questionnaire was constructed for determining students' perceptions on the outcomes of laboratory work on their cognitive, psychomotor and affective domains. The proposed survey questionnaire is categorized into three constructs, namely cognitive, psychomotor and affective domains. A reliability test using Statistical Package for Social Sciences (SPSS) indicated the following Cronbach's alpha coefficients: 0.901 (cognitive), 0.853 (psychomotor) and 0.774 (affective). These reliability indices show that the instrument has good reliability, and thus has the potential to be used in different settings.

BACKGROUND

The historical perspective of laboratory in engineering education has been discussed thoroughly by Feisel and Rosa (2005). According to the authors, most of teaching and learning in engineering education during early seventies were conducted in the laboratory where the emphasis is on learning-by-doing or hands-on laboratory. The advancement of technologies and computers has given an impact to the teaching and learning in the laboratory where computers are extensively used in simulation and remote laboratories. In this regard, Ma and Nickerson (2006) and Elawady and Tolba (2009) have divided the laboratory into hands-on, remote (or virtual) and simulation laboratories. In hands-on laboratories, students are physically present in the laboratory and engage in the real experiments which involve real materials, real instruments and real electrical components (Ma and Nickerson, 2006; Elawady and Tolba, 2009). According to Krivickas and Krivickas (2007) and Elawady and Tolba (2009), the objectives related to hands-on laboratories are conceptual understanding, design skills, professional skills and social skills.

On the other hand, in remote laboratories, students are not physically present in the laboratories. They perform the experiments and collect real data by controlling the laboratory equipment through the Internet (Feisel and Rosa, 2005; Ma and Nickerson, 2006). The objectives associated with remote laboratories are conceptual understanding and professional skills (Krivickas and Krivickas, 2007; Elawady and Tolba, 2009).

Simulated laboratories are the replication of real experiments where all the components, materials and equipment for laboratory experiments are simulated on computers (Ma and Nickerson, 2006; Elawady and Tolba, 2009). According to Feisel and Rosa (2005), simulated laboratories are useful for illustrating experimental behaviors that are difficult to be visualized by the students. Simulated laboratories also addressed objectives related to conceptual understanding and professional skills (Krivickas and Krivickas, 2007; Elawady and Tolba, 2009). Even though there are different types of laboratory, this study only focuses on the learning objectives and outcomes of hands-on laboratory.

To address the issues associated with the laboratory learning objectives and outcomes, ABET and Sloan Foundation has organized a workshop in January 2002 to formulate the learning objectives for engineering laboratories (Feisel and Peterson, 2002a; Feisel and Peterson, 2002b). The workshop were attended by experts in engineering education who are very experience in developing and teaching traditional engineering laboratories. Eventhough Feisel and Peterson (2002a) recommended the engineering educators to use these Learning Objectives for Engineering Laboratories (refer to Appendix A) to evaluate the effectiveness of the laboratory work in their existing programs, there is relatively small number of published papers that employed all the recommended Learning Objectives for Engineering Laboratories.

Literature reviews indicate that several researchers have conducted research on the learning outcomes of laboratory work on students' learning. However, these studies are not comprehensive, that is, they only focus on a particular learning domain. For example, Watai, Brodersen and Brophy (2007) conducted a test to determine students' prior knowledge in electronic concepts before the students conducted a laboratory work, which focused on cognitive domain. A study by Radin Salim, Mohd Daud and Puteh (2009) also focused on the cognitive domain. The authors conducted a knowledge test at the end of the semester in order to determine students' knowledge after performing the laboratory work. In another study, Radin Salim, Puteh and Mohd Daud (2011) conducted a survey after the students performed a laboratory work to determine students' perceptions on their practical skill levels. This study was associated with the psychomotor domain. Another researcher, Sneddon *et al.* (2008) listed the following items as the learning outcomes of a laboratory work: 1) understanding of theoretical knowledge, 2) handling of measuring tools, 3) improve the experimental knowledge and skills, 4) data analysis and problem solving skills, 5) teamwork and patience, and 6) computing skills. Even though the study by Sneddon *et al.* (2008) includes the items in the cognitive, psychomotor and affective domains, but the items in each domain are very limited. Therefore, it is important to develop a survey instrument that could be used to determine students' perceptions on the learning outcomes of laboratory work which cover all learning domains.

Several terms were used in the literature to refer to the learning outcomes of laboratory work on students' learning, such as "objectives", "outcomes", "aim" and "goals". According to Heywood (2005), it is difficult to identify the differences between learning *objectives* and *outcomes* because both terms represent statements of what the students are expected to accomplish. For example, Gronlund (1995), Pape (2004), Olds *et al*. (2005) and Soulsby (2006), stated that the course *learning objectives* are the *intended learning outcomes*. Soulsby (2006) also acknowledged that the terms objectives and outcomes are used interchangeably whereas Kennedy, Hyland and Ryan (2006) argued that the term "*intended learning outcomes*" is commonly shortened to "*learning outcomes*". Therefore, to be consistent, the term learning outcomes are used in this paper to represent the terms "aims", "goals" and "objectives" of the laboratory work discussed in the literature.

METHODOLOGY

Several levels of research methodology are applied in this study. These are:

1. Identify and categorize the learning outcomes of the laboratory work to the respective learning domains.
2. Determine the validity and the reliability of the instrument.
3. Pilot testing.

Identifying and Categorizing the Learning Outcomes

Literature related to the laboratory learning outcomes were reviewed and analyzed. Then, the identified learning outcomes were categorized into the corresponding learning domains based on the following definitions of the cognitive, psychomotor and affective domains. It should be noted that the cognitive, psychomotor and affective learning domains (also known as educational objectives or taxonomy) cannot be isolated from each other because almost all learning activities involve more than one domain (Bott, 1996; Merrit, 2008). For examples, cognitive objectives normally include some affective aspects whereas both cognitive and affective components influence the psychomotor skills (Gronlund, 1995).

Cognitive: reflect students' knowledge and thinking skills (Linn and Miller, 2005; Spurlin, Rajala and Lavelle, 2008)

Psychomotor: focus on manual tasks that require the manipulation of objects or apparatus (Bott, 1996; Merrit, 2008) which involves the coordination between the brain and body in performing the tasks (Zaghloul, 2001).

Affective: represents individual's attitude, beliefs, emotions and feelings (Bott, 1996)

In addition to the above definitions, the grouping of the Learning Objectives for Engineering Laboratories by Feisel and Rosa (2005) was used as a reference in categorizing the identified learning outcomes into the respective domains. This grouping is shown in Table 1.

Table 1: Learning objectives for engineering laboratories and the corresponding learning domains

Learning domains	Learning objectives
Cognitive	1. Instrumentation, 2. Models, 3. Experiment, 4. Data analysis, 5. Design
Psychomotor	1. Manipulation of apparatus 2. Sensory awareness
Affective and Cognitive	1. Learn from failure, 2. Creativity, 3. Safety, 4. Communication, 5. Teamwork, 6. Ethics

Source: Feisel and Rosa (2005)

Table 2 shows the identified learning outcomes of the laboratory work in the cognitive domain.

Table 2: Laboratory work learning outcomes (cognitive domain)

No.	Items
1.	Improve knowledge about theory learned in class
2.	Help to verify theory learned in class
3.	Improve ability to use formulas in solving problems / questions related to theory
4.	Improve ability to use the correct unit for the measured values
5.	Help to develop basic statistical technique (i.e. draw graph and chart)
6.	Improve understanding about safety in the lab
7.	Improve ability to analyze / discuss experimental result
8.	Improve ability to write the conclusion of the experiment
9.	Improve ability to write laboratory report

Items 1 to 4 represent the learning outcome related to "integrating the theoretical and practical aspects of a course". This is in line with O'Sullivan (2008) who stated that laboratory work is important for demonstrating principles learned in class. On the other hand, items 5 to 9 indicate the specific knowledge that could be achieved by performing the laboratory work.

Table 3 illustrates the identified learning outcomes of the laboratory work in the psychomotor domain.

Table 3: Laboratory work learning outcomes (psychomotor domain)

No.	Items
1.	Improve ability to conduct experiments
2.	Improve ability to select appropriate instruments
3.	Improve ability to plan experimental work
4.	Improve ability to construct circuits
5.	Improve ability to connect instruments
6.	Improve ability to operate the instrument (i.e. select proper range)
7.	Improve ability to take the reading of the instruments

The items in the psychomotor domain represent the practical hands-on skills that are performed by the students during the laboratory sessions. These items are comparable to the items discussed by Duit and Tesch (2010) who stated that one of the learning outcomes of laboratory work is for students to develop the skills to carry out the experiments.

Table 4 shows the identified learning outcomes of the laboratory work in the affective domain.

Table 4: Laboratory work learning outcomes (affective domain)

No.	Items
1.	Improve team working skill
2.	Improve communication skill
3.	Improve ability to learn independently
4.	Improve ethics (i.e. plagiarism, copy other students' results)
5.	Improve creativity
6.	Learn from failure
7.	Improve motivation

According to Gronlund (1995), writing learning outcomes in the affective domain is difficult because of the vagueness of the terminology used. For example, Spurlin, Rajala and Lavelle (2008) described the affective domain as the personal and social dimensions of an individual. At the higher education levels, other terms have been used by researchers to describe students' abilities to work in a team, communicate effectively, behave professionally and ethically, and perform other related skills. These terms include professional skills (Shuman, Besterfield-Sacre and Jackmcgourty, 2005), soft skills (Ministry of Higher Education, 2006), personal skills (Edward, 2002) and generic skills (Hayati and Mir, 2004; Kamsah, 2004). For the purpose of this paper, the term affective is used to represent students' personal and social aspects such as attitudes, values, team working skills and communication skills.

After categorizing the identified learning outcomes into their respective domains, the authors proceed with the procedures to ensure the validity and reliability of the proposed instrument for Measuring the Learning Outcomes of Laboratory Work (MeLOLW).

Determining the validity and the reliability of the instrument

The thinking about validity is now focuses on obtaining the evidence for a unitary validity, instead of discussing on types of validity such as content validity and face validity (Johnson and Christensen (2008). These evidences are: 1) evidence based on content, 2) evidence based on internal structure, and 3) evidence based on relation to other variables.

To ensure the validity of the proposed instrument (MeLOLW), the evidence based content was determined by having few discussions with the expert in engineering laboratory work and the expert in education. Authors' experiences as engineering educators at one of the higher learning institutions in Malaysia also contribute to the evidence based content of MeLOLW. As engineering educators, the authors also involve in monitoring and supervising students during the laboratory work.

Since all the laboratory works at this institution are traditionally conducted, where the procedures to perform the experiments are provided to students in the laboratory worksheets, the learning outcomes which are related to inquiry-based laboratory were not included in MeLOLW. Examples are: 1) to design the experiment, 2) to write procedures to perform the experiments, and 3) to write hypothesis of the experiments.

After finalizing the learning outcomes to be included in the MeLOLW, the reliability coefficients of the survey instrument were obtained using Statistical Package for Social Sciences (SPSS). The values of the Cronbach's alpha coefficients for each construct will be discussed in the result and discussion section.

Pilot testing

According to Johnson and Christensen (2008), it is important to pilot testing the survey instrument before it is used in a research study. Therefore, a pilot test was conducted to determine the suitability and to eliminate any ambiguity of the items in the MeLOLW. The participants are first-year students of a three-year program (six semesters) known as Diploma in Electronic Engineering. This program is offered by one of the higher learning institutions in Malaysia. The survey was conducted at the end of year one where the participants have completed two Electronics / Electrical Engineering Laboratory courses. A total number of 26 students participated in the pilot test.

Students' perceptions on each item in the constructs were measured using a four-point Likert scale which represent different levels of agreement (4: strongly agree, 3: agree, 2: disagree, 1: strongly disagree). The result of the pilot test will be discussed in the following section.

RESULT AND DISCUSSION

The survey instrument (MeLOLW) consists of three constructs which represent the cognitive, psychomotor and affective domains. The items in each construct are stated in the previous section (refer to Table 2 for cognitive, Table 3 for psychomotor and Table 4 for affective). Table 5 shows the Cronbach's alpha coefficients of MeLOLW which were obtained using SPSS reliability test.

Table 5: Cronbach's alpha coefficients of MeLOLW

Learning domain	Cronbach's alpha coefficients
Cognitive	0.901
Psychomotor	0.853
Affective	0.774

The result in Table 5 indicates that the survey instrument has good reliability, and thus has the potential to be used in different settings.

The pilot test for determining the effectiveness and the usefulness of MeLOLW was administered at the end of Semester 2, session 2011/2012. Twenty six (26) students who have completed two Electronics / Electrical Engineering Laboratory courses participated in the pilot test. The results of the pilot test which were analyzed using SPSS are shown in Table 6, 7 and 8.

Table 6 shows the items in the cognitive domain and their corresponding mean.

Table 6: Learning outcomes of the laboratory work (cognitive domain)

No.	Items	Mean
1.	Improve knowledge about theory learned in class	3.69
2.	Help to verify theory learned in class	3.58
3.	Improve ability to use formulas in solving problems / questions related to theory	3.12
4.	Improve ability to use the correct unit for the measured values	3.38
5.	Help to develop basic statistical technique (i.e. draw graph and chart)	3.23
6.	Improve understanding about safety in the lab	3.42
7.	Improve ability to analyze/discuss experimental result	3.50
8.	Improve ability to write conclusion of the experiment	3.15
9.	Improve ability to write laboratory report	3.15

The overall mean for all the items in the cognitive domain is 3.36. The result suggests that, students perceived the learning outcomes of the laboratory work in the cognitive domain have been achieved. Item 1 and 2 indicate a very high mean which indicate the students agreed that laboratory work help them to improve their knowledge as well as to verify the theory they learned in class.

Table 7 illustrates the items and the result related to the psychomotor domain.

Table 7: Learning outcomes of the laboratory work (psychomotor)

No.	Items	Mean
1.	Improve ability to conduct experiments	3.58
2.	Improve ability to select appropriate instruments	3.65
3.	Improve ability to plan experimental work	3.62
4.	Improve ability to construct circuits	3.38
5.	Improve ability to connect instruments	3.35
6.	Improve ability to operate the instrument (i.e. select proper range)	3.42
7.	Improve ability to take the reading of the instruments	3.62

The overall mean for all the items in the psychomotor domain is 3.52. The result suggests that, students perceived the learning outcomes of the laboratory work in the psychomotor domain have been achieved.

The items and their corresponding mean in the affective domain are tabulated in Table 8.

Table 8: Learning outcomes of the laboratory work (affective)

No.	Items	Mean
1.	Improve team working skill	3.69
2.	Improve communication skill	3.69
3.	Improve ability to learn independently	3.42
4.	Improve ethics (i.e. plagiarism, copy others results)	3.31
5.	Improve creativity	3.42
6.	Learn from failure	3.62
7.	Improve motivation	3.69

The overall mean of all the items is 3.55. This indicates that a very high percentage of the students perceived that laboratory work give benefit to them with respect to affective domain. Item 1, 2, and 7 recorded a very high mean which indicates that the laboratory work could improve students' team working and communication skills as well as their motivation. This finding supports claimed by Hayati and Mir (2004), Feisel and Rosa (2005), Krivickas and Krivickas (2007) and Casas and Hoyo (2009) who reported that laboratory work could improve students' team working and communication skills. The result also reinforced finding by Davies (2008) who argued that the laboratory work could motivate students to learn the related theoretical course.

CONCLUSION

This paper proposed an instrument (known as MeLOLW) for measuring students' perceptions on the learning outcomes of laboratory work on their cognitive, psychomotor and affective domains. The process of developing, validating and pilot testing MeLOWL were discussed. The items in MeLOLW were categorized into three construct namely cognitive, psychomotor and affective. A reliability test using SPSS indicated the following Cronbach's alpha coefficients: 0.901 (cognitive), 0.853 (psychomotor) and 0.774 (affective). The result of the pilot test also indicates a high mean for all the items. The high reliability indices and the result of the pilot test show that the proposed survey instrument has good reliability and effective, and therefore has the potential to be used in different setting.

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Appendix A

Learning Objectives for Engineering Laboratories

Objectives	Criteria	Description
1	Instrumentation	Apply appropriate sensors, instrumentation, and/or software tools to make measurements of physical quantities.
2	Models	Identify the strengths and limitations of theoretical models as predictors of real world behaviors. This may include evaluating whether a theory adequately describes a physical event and establishing or validating a relationship between measured data and underlying physical principles.
3	Experiment	Devise an experimental approach, specify appropriate equipment and procedures, implement these procedures, and interpret the resulting data to characterize an engineering material, component, or system.
4	Data Analysis	Demonstrate the ability to collect, analyze, and interpret data, and to form and support conclusions. Make order of magnitude judgments, and know measurement unit systems and conversions.
5	Design	Design, build, or assemble a part, product, or system, including using specific methodologies, equipment, or materials; meeting client requirements; developing system specifications from requirements; and testing and debugging a prototype, system, or process using appropriate tools to satisfy requirements.
6	Learn from Failure	Recognize unsuccessful outcomes due to faulty equipment, parts, code, construction, process, or design, and then re-engineer effective solutions.
7	Creativity	Demonstrate appropriate levels of independent thought, creativity, and capability in real-world problem solving.
8	Psychomotor	Demonstrate competence in selection, modification, and operation of appropriate engineering tools and resources.
9	Safety	Recognize health, safety, and environmental issues related to technological processes and activities, and deal with them responsibly.

10	Communication	Communicate effectively about laboratory work with a specific audience, both orally and in writing, at levels ranging from executive summaries to comprehensive technical reports.
11	Teamwork	Work effectively in teams, including structure individual and joint accountability; assign roles, responsibilities, and tasks; monitor progress; meet deadlines; and integrate individual contributions into a final deliverable.
12	Ethics in the Lab	Behave with highest ethical standards, including reporting information objectively and interacting with integrity.
13	Sensory awareness	Use the human senses to gather information and to make sound engineering judgments in formulating conclusions about real-world problems.

Source: Feisel and Peterson (2002a) and Feisel and Peterson (2002b)