Assessing students' practical intelligence in hands-on electrical laboratory via psychomotor domain by using engineers automated testing kit

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Abstract: Experience in the engineering lab is important for engineering students in which they can improve the understanding of engineering concepts in theory they have learned. The author does not known what really occur in typical laboratory although the purpose of the laboratory is to gain experience and learn the craft. The student will develop practical intelligence either intentionally or unintentionally, when perform the tasks in laboratory. Psychomotor domain is likely related to practical experience gained by engineering students that perform hands-on laboratory class. The task in psychomotor domain might be able to be measured in effectively by compare the learning utility of hands-on laboratory class. In this research, the authors proposed of using Engineers Automated Testing Kit in testing practical experience (psychomotor domain) after performing laboratory classes. The practical exercise with the Testing Kit has demonstrated that first year electrical engineering student's (experiment group) gained significant practical experience from laboratory class and able to score significantly compared to the control group. This technique can provide a means to measure that elusive component in the engineering lab experience is also known by most of people as "practical experience". Methodologies and detail results for this research are described in this paper.

Keywords: Practical intelligence; Engineering technology; Psychomotor domain model; Laboratory classes; Practical skills

1. INTRODUCTION

Malaysian Technical University (MTU) (UniMAP, UteM, UMP and UTHM) established hands-on concepts in their Engineering Technology courses which is 40% of theoretical components and 60% of practical components. However, Malaysian Qualifications Agency (MQA) is concern about the implementation of the 40-60 concepts. Practical class components are mostly related to hands-on laboratory classes where laboratory experiment is critical in the education for engineering technologist; hence, the experiments are integrated in the engineering curriculum to prepare students for engineering experience and practice prior to their graduation [1]. To fulfill the MQA requirement, the laboratory class components are very important learning experiences, which can be used to effectively teach the link between real-world and theory behavior of engineering systems [2]. Based on this concern, this paper reports on a fundamental investigation of some learning phenomena in conventional hands-on laboratories that arose from the question "What do students really learn in laboratory classes' experiences and how the experiences be measured?" The researchers started a project to explore this issue and also to understand more the traditional laboratory classes' outcome of practical learning. The authors came across a substantial body of research on the notion of 'practical intelligence' (PI) that relates to the ability of a person to solve practical issues in a given domain. Psychologists evolved PI measurement instruments as part of an extended discipline-wide debate on predicting on-the-job performance of people using results from psychometric tests. The authors found that the authors could apply these techniques to measure significant gains in PI resulting from participation in hands-on laboratory tasks. PI is unrelated to the conventional assessment (examinations, tests, lab reports, tutorial exercises) results for students'. More interestingly, the authors found evidence that suggests the possibility that PI can predict students' ability to perform fault diagnosis tasks.

However, the way of assessment practices using reports and test for assessing laboratory experiences can only assess students' achievement in cognitive domain [3]. The concern of assessing psychomotor in engineering laboratory still arose by many researchers [4][5][6]. The methods that exist to evaluate engineering technology student for laboratory experience does not include the assessment of the psychomotor domain due to lack of appropriate measuring instruments [3]. Therefore the proposed method of assessing psychomotor domain is to prove that the method of measuring hands-on or practical components of learning is totally different to cognitive domain.

For the first time, therefore, the authors can demonstrate that there are real advantages inherent in hands-on laboratory classes and the authors can measure this advantage. What the authors can learn from this work is that students' learning in laboratory classes is not what the authors have come to expect. There is still much to discover and this study will provide some research tools to enable others to follow similar investigations.

1.1 Assessing Practical Intelligence via Psychomotor Domain

University put under enormous pressure to produce graduates who are employed as the number of unemployed graduates is growing. Industries parties have found that most of the employee are less skilled and less the experienced engineers because of the difficulty to find suitable candidates and also voiced that the engineering graduates do not seem to concern of the necessary experience or PI in the working [2]. PI is often referred to a person's ability to solve practical challenges within a particular domain. The lack of PI may be caused by the way in which explicit knowledge is valued and then evaluated in the education of engineering through tests, examinations, tutorial exercises, laboratory reports. The lack of effective evaluation of the psychomotor domain shows that implicit devaluation in practical intelligence that could affect the ability of engineering students' to obtain and value PI.

Therefore in this study, the authors propose a new method of assessment psychomotor domain for engineering technology students to represent the outcomes of practical intelligence, after performing fundamental electrical laboratory classes. The measuring of practical intelligence approach (or novices-experts approach) [7] will be used in designing the assessment instruments (Engineers Automated Testing Kit); based on the observation of behaviors' of students (novices)/experts and novices/experts representative work-related situations.

2. THEORETICAL BASIS

2.1 Practical Intelligence in Hands-On Laboratory

Currently, most assessment involves in the evaluation of laboratory work for engineering students' only in explicitly specified learning outcomes, explicit propositional knowledge that can be written in a laboratory report or examination, or tested in a quiz or multiple choice test. In evaluating the laboratory class effectiveness, student evaluations or opinions may also be included [1][8][9]. Explicit propositional knowledge is represented by words or symbols: a mathematical equation is an example. This sentence is another representation. There are, however, other forms of knowledge and learning that could also play a part. Eraut [10] described implicit learning in terms of experience. Memories of personal experience accumulate and influence subsequent behavior, though not necessarily in a way that the person can explain. Polanyi [11] described this as tacit knowledge, knowledge that the authors do not know that the authors know, such as the ability to ride a bicycle.

Learning can also be characterized by the level of intentionality. For instance, students perform laboratory classes with intentionally to learn what they read in the laboratory handout, and they acquired the learning outcomes. However, sometimes they unintentionally learn something new for them, such as the way to run the machine appropriately through practical session of running the machine. Another example, a child's deliberate attempts to learn to ride a bicycle represent intentional learning of implicit knowledge. On the other hand, it is often observed that a child's ability to ride the bicycle improves significantly after a rest period following what might have been a series of partial successes, even failures resulting in minor injuries. Learning has occurred during the rest period without any conscious participation by the learner: this is referred to as incidental learning.

During the practical sessions, even though the students are given laboratory handout, usually they learn beyond the stated objectives. By their previous experience, unintentional knowledge and many other things will come to increase in their experience and helpful in achieving laboratory objectives, or students desired objectives: completed the laboratory sessions quickly, even giving marks seem not to be too important. For instance in electronics laboratory, the unintentional learning that the students gain through constructing electrical circuit might include convenient ways to strip connecting wires or ways to make reliable electrical connections, which is practical knowledge, and one way to measure this learning is through the notion of practical intelligence, originated by Sternberg, Wagner and their colleagues [7]. Practical intelligence enables action with appropriate results.

From the literature review, the authors found and concluded that practical intelligence can be effectively measured [7][12]. Other researchers [4][5][6] shows that students' practical skills or practical intelligence can be measured effectively via psychomotor domain and assessment method would specifically assess students' experience and practical skills with respect to laboratory experiments.

2.2 Psychomotor Domain Model

Skills in the psychomotor domain describe the ability to physically manipulate a tool or instrument like a hand or a hammer. Usually the development of behavior or skill is strongly related to psychomotor objectives. Thus, students' practical skills and practical intelligence in the laboratory are associated with the psychomotor domain. This domain focuses on manual task that needs the manipulation of physical and objects activities [13]. In this study, the authors used the psychomotor domain model (PDM) proposed by Ferris & Aziz [14]. The model in the PDM, maps the distribution of skills of students in performing laboratory experiment [4].

The psychomotor domain model introduced by [14] have seven levels of psychomotor domain hierarchy related to laboratory experiment in engineering technology education (refer to Table 1). According to Kennedy, Hyland & Ryan [15], this psychomotor domain model is specific for engineering technology students and could be used to assess the physical actions of engineers.

2.3 Testing Practical Intelligence: Novices-Experts Approach

Sternberg and his colleagues [7] used a novices-experts approach in constructing their instruments. The expert will share the most remarkable experience as well as failure experience in the stated domain, for identifying representative work-related situations. The most remarkable experience as well as failure experience will be collected from the experts by interviewing them personally and asked them to propose describe alternative ways of solving the problems they had confronted.

On novices' side, the experience of novices are to be explored by asking them to describe how they handled the problems, and how their handling of the incident might have set themselves apart from other person who might have handled the incident differently. Thus, the novices were asked to describe both their own solutions and a variety of alternative solutions to the same problem. Based on the interviews and the data of behavior/skills collected a set of practical intelligence testing instrument was constructed that required experts to make judgment and decisions [16].

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	Handle objects without damage to either the object or other objects in its environment or hazard to any person.
3	Basic operation 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 tools for performing a range of tasks of the kind for which the tools were designed.
5	Expert operation of tools	Ability to use rapidly, efficiently, effectively and safely to perform work tasks on a regular basis.
6	Planning of work operations	Ability of competent to do specification work and perform the necessary transformation.
7	Evaluation of outputs and planning for improvement	Ability of competent to look at a finished output product and review the product for quality of manufacture

Source : [4][14]

In this study, the authors have designing and fabricating an automated practical intelligence instruments (Engineers Automated Testing Kit) which complies with the psychomotor domain model introduced by Ferris & Aziz [14]. In developing the instrument, the experts' behavior in constructing electrical circuit (activities of practical technical problem solving) is in-depth observed. After that, an interview with the experts will be conducted, to explore what are in the minds of experts to solve the practical problems, to establish a valid and reliable practical intelligence instrument. After the instrument fabricated, then novices will test the instrument. The outcomes of practical intelligence can be measured by calculating the difference between novices' and experts' ratings; zero difference shows novices' close to experts' practical intelligence [17]. The anticipated outcome is that the results could demonstrate the psychomotor domain of individual students; a novel method of laboratory classes' assessment by measuring individual practical intelligence acquired after performing the laboratory tasks.

3. LABORATORY CLASS DESCRIPTION

Introductory laboratory classes in electrical engineering fundamentals (PLT105 Electrical Circuit Theory) is chosen as a research medium of this study. This choice was determined partly by our own interests in robotics automation and partly because these classes are offered twice annually providing plenty of opportunities for observation and testing. Approximately more than 100 students take these classes annually providing potentially large sample sizes for testing and evaluation. The purpose of these laboratories is to introduce engineering students to fundamental concepts and applications of electrical and electronic engineering in a practical and enjoyable way.

The laboratories build on theory covered in lectures, reinforcing the concepts needed in the design of systems. The laboratory sequence consists of four experiments: Crystal Radio, Diode and Optical Sensor, Operational Amplifiers, and Digital Logic. In these experiments, the students have to develop the fundamental skills of practical electronics to reading a circuit diagram and using it to construct a working circuit, understanding the fundamental components in electronic engineering such as resistors, capacitors, inductors, diodes, transistors, operational amplifiers, and constructing a control system capable of guiding a vehicle around a track.

4. OBJECTIVE AND HYPOTHESIS

The authors wish to explore the way for measuring experience gained in hands-on components of laboratory classes. Thus, the research objective is to explore and propose ways to measure changes in practical intelligence due to the practical activities via psychomotor domain. In detail, the sub objectives are:

i. To develop automated measuring instrument (Engineers Automated Testing Kit) based on the students' behavior in performing laboratory classes
ii. To experimentally apply the Engineers Automated Testing Kit to experts; to develop reference score
iii. To experimentally apply the Engineers Automated Testing Kit to experiment and control group of students; to develop experimental score
iv. To analyze the students' score of practical intelligence acquired based on the experts' score as a reference score.
v. To propose guideline or awareness towards greater industry-readiness to the undergraduate students, therefore they will have some motivation to prepare themselves for industry-live in future after leaving university-live.

For this purpose, diagnosing or troubleshooting laboratory setting or faults is the tasks that need the high level of practical minds or practical intelligence. Therefore, the authors propose to test the following hypothesis:

"That there is no statistically significant difference in the practical intelligence gained by students who perform the laboratory exercises and a control group who do not perform the laboratory exercises."

If the authors can prove that the hypothesis is false with a high degree of probability, and then the authors can be confident that the novices-experts approach is succeed in assessing practical intelligence in the context of diagnosing faults in the relevant equipment and that this psychomotor domain can be assessed. The method of measuring would then provide a powerful new means to assess the effectiveness of engineering technology laboratory classes.

5. METHODOLOGY

The authors developed an instrument to measure practical intelligence in the context of laboratory classes that support the unit Electrical Circuit Theory (PLT105). The unit is compulsory for all the first year students (more than 100 students) commencing engineering technology each year at UniMAP. There are two academic semester for each academic year, thus students can choose which semester they wish to perform the subject PLT105. In the second half of 2015, the number of students enrolled PLT105 are 69 students (n=69) (the experiment group). Meanwhile another group of students who yet to register PLT105 (n=57) (to enroll in the same subject in the following semester), as a control group will do the exercises, similar to the experimental group.

Seven domain experts such as lecturer, laboratory demonstrators and electronics technicians provided reference scores as mentioned above.

The scope of this study includes several levels of research methodology. These are:

1. Identifying the practical intelligence acquired
2. Designing and fabricating measuring instrument (Engineers Automated Testing Kit)

5.1 Identifying Practical Intelligence Acquired

In constructing the practical intelligence psychomotor instrument, laboratory worksheets in PLT205 were analyzed and reviewed. The same procedure and tasks for each worksheet laboratories were collected in accordance with practical skills by students during the experiment. Next, the authors compared the practical skills that have been identified with the PDM listed in Table 2 in order to categorize the practical skills according to specified levels.

Task 1, 2, 4, 5 and 10 in Table 2 could be easily mapped to PDM Level 1 (recognize). For tasks 7 and 8 are combination level, are mapped to PDM Level 1 (recognize), Level 2 (handling) and Level 3 (basic operation). For these tasks, the student should recognize the material, able to handle or hold the material properly and do the basic tasks such as plug-in appropriately. Usually, the student will be able to do the tasks successfully. However, to do the tasks 3, 6 and 9 required student ability and competent (i.e practical skills and practical intelligence). For example, to strip wire insulator, the student should recognize the appropriate tools (Level 1), able to handle and use the tools (Level 2) and competent to strip wire insulator (Level 4) because in many cases, the entire wire is cut instead of the insulator is cut. Similar cases to the tasks 6 and 9. Level 5 (expert operation) of the PDM are unrelated to the tasks given because the practical skills in PLT105 only involve with the basic instruments. Task 11 is just to display total time to complete the experiment.

5.2 Practical Intelligence Instrument (Engineers Automated Testing Kit)

The practical intelligence instrument (Engineers Automated Testing Kit) consists of a set of domain-related psychomotor tasks, to construct simple electrical circuits. The practical task consisted of a partially completed circuit in which a power supply provides power for a LED light. In designing the instrument kit, the tasks given would provide sufficient variation to provide statistically meaningful results.

Figure 1 shows a photograph of the Engineers Automated Testing Kit for the circuit construction task. This psychomotor task is required students to construct the circuit, based on the circuit diagram given, diagnose the error on the circuit throughout the tasks and complete the necessary connections until the LED lights are ON.

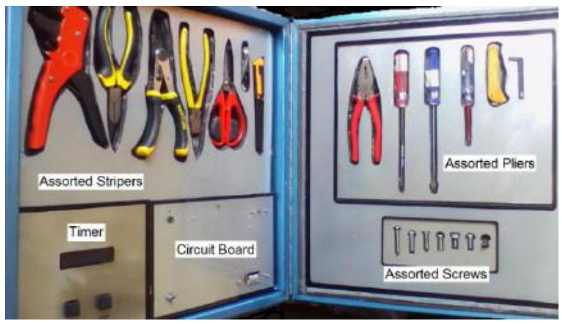

Figure 1. Engineers Automated Testing Kit

In completing the circuit, a student is given assorted of wires, wire stripers, screws, screw drivers, circuit board,

Table 2: Psychomotor tasks vs. mapping of the skills to the PDM

	Appropriate tasks	Practical Intelligence Acquired	Mapping to PDM level
1	turn ON the circuit panel	start the test to count the marks	Recognize (Level 1)
2	choose wire	choose appropriate wires to be striped	Recognize (Level 1)
3	choose wire striper	choose appropriate wire striper and strip the wire insulation	Recognize (Level 1)/ Handling (Level 2) / Competent operation (Level 4)
4	choose screw	Choose appropriate screw based on a diameter of nut.	Recognize (Level 1)
5	choose screw driver	choose appropriate screw driver	Recognize (Level 1)
6	connect the wire	connect the uninsulated wire to the circuit board using the screw and screw driver chosen	Recognize (Level 1)/ Handling (Level 2) / Competent operation (Level 4)
7	plug-in LED	plug in LED into the circuit board	Recognize (Level 1)/ Handling (Level 2) / Basic operation (Level 3)
8	plug-in resistor	choose the appropriate resistor and plug into the appropriate hole	Recognize (Level 1)/ Handling (Level 2) / Basic operation (Level 3)
9	choose joined wire	choose the appropriate joined wire and complete the circuit	Recognize (Level 1)/ Handling (Level 2) / Competent operation (Level 4)
10	turn OFF the circuit panel	If the LED lights ON, the score will appear on the LED display.	Recognize (Level 1)
11	total time completed	LED display shows total time	Not available

resistors and connected wires, which each and every item can be used to complete the circuit. Each of the materials and tools are fixed in the Testing Kit box and connected to electronics sensor. Each of the assorted materials and tools indicated as response items, with random score between 1–7 (depend on the number of items). To create the response items, the authors have do the in-depth observation on students' behavior during performing laboratory classes' activity, included student's highly appropriate responses and also common inappropriate responses. The test starts by clicking the ON button. When the student chooses and takes any tool for the first time to do the task, the mark will calculate into his account. He has to choose the appropriate materials and tools, and there is no wrong answer or not trial and error. Their performance was scored by calculating how many of the faults were diagnosed and corrected, which tools they *first* chose to use (appropriate or otherwise), which components they *first* chose to try using, and their time to complete (if they managed to before the 20 minute time limit). The circuit complete if the LED lights ON; by clicking OFF button, the LED display will show the marks collected. The data collected will show student's score, by calculating the deviation from the average responses of a number of domain experts such as senior technicians, practiced engineers and experienced laboratory demonstrators. The appropriate selection (appropriate score close to experts score) shows his level of practical intelligence and practical skills ability.

6. RESULTS AND DISCUSSIONS

The Engineers Automated Testing Kit instrument was tested with 69 first year students of Robotics and Automation Technology (experiment group) and 57 first year students of Industrial Power Technology (control group), was analyzed using descriptive statistics for frequencies. Participants merely applied what they thought was the most appropriate response tasks. The mean scores of the psychomotor tasks inventory are listed in Table 3. SPSS Software is used to perform a uni-variate analysis of variance (ANOVA). The analysis is to determine whether there was a difference among the two group of study (experiment and control group) with regard to the psychomotor domain variable. The results demonstrated practical experience give advantages to the experiment group students than the control group students, especially for the tasks 3, 6 and 9.

The researchers used a t-test to analyze the effect of psychomotor tasks. Results indicated there are significant difference between experiment and control groups of students in psychomotor tasks scores in cases 3, 6 and 9 ($p < .001$). The results shows for the tasks 3, 6 and 9, the students apply up to the Level 3 PDM (competent operation). In this PDM level, the advantages of practical intelligence and skills are very helpful for the students to solve the tasks appropriately. It is assume that the control group students did not have the advantages.

Table 3: Means, Standard Deviations, and t-Test

Tasks	Sample	Control	Experiment	t
1. turn ON the circuit panel				
2. choose wire				
M	3.24	2.95	3.58	2.19*
SD	0.77	0.80	0.65	
3. choose wire striper				
M	3.36	3.25	3.90	2.67***
SD	0.77	0.74	0.75	
4. choose screw				
M	1.87	1.56	1.96	2.26*
SD	0.68	0.72	0.69	
5. choose screw driver				
M	2.27	1.78	2.38	2.23*
SD	0.79	0.75	0.64	
6. connect the wire				
M	3.14	1.83	2.38	2.79***
SD	0.84	0.65	0.74	
7. plug-in LED				
M	3.48	3.58	2.95	3.09
SD	0.77	0.81	0.95	
8. plug-in resistor				
M	2.77	3.55	3.90	3.02
SD	0.86	0.94	0.71	
9. choose joined wire				
M	1.77	1.65	1.91	2.66***
SD	0.80	0.74	0.72	
10. turn OFF the circuit panel				
11. total time complete				
M	2.07	1.83	2.38	2.96***
SD	0.72	0.75	0.67	

Note: *$p < .05$; ***$p < .001$

The researchers also used a t-test to analyze the similarity of the practical intelligence between the both groups. The tasks 2, 4 and 5 demonstrated that the experiment group had slightly higher on psychomotor tasks, however there is no significant differences between the two groups ($p<.05$). Results showed that in tasks 2, 4 and 5, the mean scores of the experiment group were significantly higher than the mean scores of the control group. Finally, the mean scores of the time taken to complete the overall tasks were higher for the experiment group. Then, it is concluded that he results of this investigation demonstrated that the original null hypothesis was false. It can be concluded that PI via psychomotor domain successfully be measured by comparing the level of rating between participants' and experts' score.

7. CONCLUSIONS

In conclusion the authors succeeded to assess differences experience acquired by engineering technology students in performing laboratory classes, by using Practical intelligence instrument (Engineers Automated Testing Kit). In developing the model of measuring PI via psychomotor domain, the PDM model proposed by Ferris and Aziz [14] was used. Practical intelligence instrument was applied to explore students' ability to construct and develop the circuit in the kit, by categorizing the practical skills. Thus this paper shows there are strong possibility to assess practical intelligence via psychomotor domain that has not been assessed or measured in the past.

Similar to Salim and her colleague [4], it is found that that the current assessment method which only relies on the laboratory report should be revised and are no longer suitable for current education scenario. The new assessment method should specifically assess students' experiences and practical skills with respect to laboratory experiments. The new method of assessment should be established as a third means in assessing the experience acquired in performing engineering laboratory class, beyond the established methods of comparing student performance in explicit assessment tasks (e.g. tests, reports) and measurement of student perceptions of their laboratory experience.

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