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Novel Approach for Assessing Psychomotor Domain in Engineering Technology Courses

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Abstract: Evaluation of laboratory experiences of engineering and engineering technology students do not include theassessment of psychomotor domain due to lack of suitable measuring tool. This is despite the importance of this domain in engineering and engineering technology courses. Current assessment practices using reports and test for assessing laboratory experiences in engineering technology courses can only assess student's achievement in the cognitive domain. A new assessment method is needed to assess that elusive component of laboratory experiences in engineering technology referred to by most people as "hands-on practical experience". Existing techniques for measuring psychomotor skills that have emerged from attempts to improve selection in recruitment processes may provide a potentially useful tool for such a purpose. The aim of this study is to develop ways to test changes in practical experience in order to assess unintentional learning related to classic psychomotor skills in engineering technology laboratory classes. The methodology used to develop the instrument is described and empirical data supporting its validity are presented.

Key words: Psychomotor domain, cognitive domain, hands-on experience, practical experience, aboratory classes

INTRODUCTION

Engineers have been contributing substantially to the development of every nation including Malaysia and are expected to continue to play a pivotal role in the future (United Nations Educational, Scientific and Cultural Organization (Wall, 2010). However, with the changing industry profile and the country migration into the k-economy, new breeds of engineering technical workforce in addition to the typical engineering professionals are demanded to support the emerging needs. With its migration to the k-economy Malaysia needs greater number of highly competent engineering technical workforce. Efforts to boost the Malaysian engineering technical workforce is embedded in the country's Human Resource Plan that focuses on the engineering technology path for producing the new breed of engineering technical workforce. For this purpose, the Malaysian engineering qualifications framework and occupational grade is enhanced from three to four categories by the introduction of a new grade called engineering technologist. The engineering technology path was introduced and facilitated by providing greater support for the Technical Education and Vocational Training (TEVT) sector. The TEVT sector is also being revamped to provide more access and to be more attractive to high ability students. For example, the ministry of education is upgrading vocational schools to vocational colleges, establishing community colleges and university colleges in support of the vocational education and training sector. Another agency, the Majlis Amanah Rakyat (MARA) has set up Universiti Kuala Lumpur that provides pathways through engineering technology path and a number of private institutions of higher learning that are also offering programmes in this area. The engineering technology path is expected to produce the necessary engineering and technical workforce that can better meet the needs of our developing nation.

Developing practical and hands-on competence of engineering students: For engineering students, experience in the engineering laboratory is an important component of their trainings for hand-on competence. By attending laboratory classes and handling (working with) the equipment, the students are likely to have greater appreciations towards them; be it in appearance or

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function. With the high cost of traditional or hands-on laboratory classes and the need for flexible learning, there has been a trend towards providing online laboratory classes through remote access or simulated mode. Online laboratory classes have been made possible through advancements in software and communication technologies (Trevelyan, 2007; Razali, 2015). Research suggest that these laboratory experiences are just as likely to enhance understanding of related concepts for which students have learned in theory as traditional hands-on laboratory classes (Lindsay and Good, 2005; Trevelyan and Razali, 2012) despite differences in the way students experience on-line and simulation labs.

In typical hands-on laboratory classes which the researchers have observed, students are usually divided into groups of four or five people and they accomplish a task together. Sometimes, not every student has contact with or handles the equipment. In contrast, a remote access laboratory normally provides an opportunity for every individual student to run the laboratory remotely (Razali, 2015). Thus although, the aim of the laboratory work is to give opportunities for students to learn and understand engineering concepts, it is not known that actually happens in a typical laboratory class. Furthermore, our current research on engineering practice indicates that there are few detailed reports on engineering practice (Trevelyan, 2007). Therefore, it is not easy to decide which laboratory experiences contribute towards the foundation for engineering practice. The researchers cannot be sure about what students will miss or gain when the researchers move from hands-on labs to on-line labs or simulations.

It is accepted that practical know-how is essential for high achievement in the workplace (Somech and Bogler, 1999). Sternberg and Wagner (1993) proposed that this type of know-how or what they have called ‘practical intelligence’ is closely related to what Polanyi (1966) has called ‘tacit knowledge’ which it is not openly expressed or stated and it usually is not taught directly.

Our research on engineering practice confirms the importance of unwritten know-how. Careful studies of engineering practice have revealed that extensive technical knowledge is needed (Trevelyan, 2007; Razali, 2015). Most of this knowledge is acquired after completing university courses and much of it is surprisingly basic. For example, engineers need to know the components and materials used in their discipline as practiced within a given firm, at least to the extent that they can recognize components and understand what they are used for. Much of this knowledge is so relatively simple on the one hand and so specific to a particular firm or industry sector on the other hand, that it would not be appropriate to attempt to teach it in university engineering courses. However, students need to appreciate the significance of this ‘implicit’ knowledge or ‘practical intelligence’ in engineering practice. However, since engineering courses restrict most assessment to explicit knowledge (the students have to write or speak to convey their knowledge), it is possible that the perceived relative value of practical experience and tacit knowledge may be reduced in the view of students. This might help to explain why employers often criticize the quality of the practical skills of engineering graduates (Razali, 2015).

Through, their laboratory experience, the researchers expect that students may acquire practical experience. It is possible they may learn enough for troubleshooting: to be able to detect and solve problems or diagnose faults in the equipment. This experience can be developed either intentionally or unintentionally and some researchers suggest that unintentional learning is an important aspect of laboratory work (Christiansen and Rump, 2007). While laboratory classes have been evaluated previously by assessing explicit knowledge (in reports and test answer scripts) and through student opinion of the laboratory class experience (Razali, 2015), the researchers have not been able to find any measurements of unintentional learning such as ‘practical intelligence’. The question is, do the students who gain experience during their laboratory classes possess a high level of implicit and tacit knowledge gained through unintentional learning that allow them to diagnose the faults of equipment. Therefore, in this study, the researchers examine unintentional learning through experience of laboratory work and the subsequent ability to diagnose equipment faults.

Experience in laboratory classes

The value of laboratory experience: One of the most important factors in forming engineering graduate qualities is the practical component of the engineering curriculum. Laboratory classes are valuable learning experiences which can be used in an attempt to teach the link between practical skills and theory effectively. Work in the engineering laboratory environment provides students with opportunities to validate conceptual knowledge, to work collaboratively to interact with equipment, to learn by trial and error, to perform analysis on experimental data and how to operate tools and equipment safely. In a laboratory class, their environment is different compared to other learning modes such as

Table 1: Skills in Psychomotor Domain

Parameters	Variables	Description
P1	Perception	Detect, describe, differentiate, isolate, distinguish, choose, select, relate, identify
P2	Set	Begin, proceed, explain, move, react, state, show, display, volunteering
P3	Guided response	Copy, trace, react, respond, reproduce, follow
P4	Mechanism	Assemble, measure, mix, calibrate, dismantle, display, construct, grind, manipulate, mend, fix, heat, sketch, organize
P5	Complex overt response	Assemble, calibrate, construct, build, display, dismantle, mend, fix, measure, manipulate, sketch, mix, organize
P6	Adaptation	Alter, adapt, vary, change, rearrange, reorganize, revise
P7	Origination	Arrange, originate, create, build, construct, design, compose, combine, initiate

lectures or tutorials. Students engage with real hardware, components and materials. They embed their learning into a different context and construct different knowledge as a result (Christiansen and Rump, 2007; Razali, 2015).

There has been a long debate on whether, new technologies can replace conventional methods of delivering laboratory classes. It is clear that the choice of laboratory technologies, i.e., simulation or remote laboratories could change the economics of engineering education and it is also clear that changing the technology could change the effectiveness of education. Researchers advocating hands-on labs think that engineer needs to have contact with the apparatus and labs should include the possibility of unexpected data occurring as the result of apparatus problems, noise or uncontrollable real-world variables. Simulation advocates often begin by invoking the spectre of cost and point out that hands-on laboratories take-up space, impose time and location constraints. Many educators claim that simulation is not only cheaper but it is also better, in that more laboratories can be conducted than with hands-on laboratories.

In contrast, a serious concern was that valuable practical experience would be lost by using a simulation (Nedic *et al*., 2003). For example, they point out that proficiency in the use of basic equipment such as oscilloscopes and signal generators is an important skill for engineers. Handling real components and taking the necessary precautions when circuit-building, are important abilities. For instance, the need to connect a power supply correctly reinforces the differences between active and passive components in a way which is lost on the simulator. Finally, there was a concern that students would place a large premium on the use of real equipment and that the place of practical work in helping to bridge the gap between theory and reality may be lost (Lindsay and Good, 2005). Although, the debate continues on the best methods for delivering laboratory classes, researchers generally advocate both modes and agree on the importance of gaining experience through hands-on laboratory work and express concern about the loss of valuable practical experience resulting from increased use of simulation and on-line labs (Christiansen and Rump, 2007; Razali, 2015).

Assessing practical experience: measuring achievement in the psychomotor domain: Researchers have shown that psychomotor domain in the form of practical experience can be effectively measured (Razali, 2015). Psychologists have debated the merit of practical experience testing instruments for predicting job performance. This debate has been driven by the search for psychometric tests that can better predict the performance of a potential employee being recruited for a particular occupation.

Proponents of general intelligence as the best predictor of job performance (Schmidt and Hunter, 1993) argue that practical intelligence is simply the result of on-the-job learning. General intelligence is the best predictor, they argue, of the ability to learn and fast learners will acquire job-specific knowledge faster. On the other hand, proponents of practical experience argue that personality tests in combination with practical experience measurement provide a more accurate predictor of ultimate job performance. Job specific tests are expensive to research and create and still require high levels of cognitive and psychomotor ability to comprehend the questions correctly. Testing practical experience is still not widely accepted as a recruitment selection tool.

In our situation, however, the researchers are not attempting to make forward predictions on the basis of practical experience measurement. The researchers only wish to measure skills in the psychomotor domain: the acquisition of practical experience in a relatively constrained situation, a sequence of planned laboratory experiments. Table 1 shows the related skills in psychomotor domain. This research only focuses on the domain of Perception (P1), set (P2), guided response (P3) and mechanism (P4).

A typical practical experience testing instrument consists of between 5 and 20 hypothetical situations described by text and diagrams and closely related to the context in which the practical experience would be applied. Between 5 and 15 response items follow each description. Each response item suggests a potentially appropriate course of action in response to the situation described. For example, presented with a description of a circuit which is not operating correctly, the response items might be:

- Check that the power supply is switched on
- Check the power supply connections to the circuit
- Check the colour codes on the resistors to ensure they have been chosen correctly
- Replace the multimeter leads
- Check the connection between the multimeter leads and the testing points

In the test instrument, each response item has a rating scale (typically 1 = very inappropriate to 7 = very appropriate). Participants are asked to rate the importance of each item.

MATERIALS AND METHODS

Instrument development methodology

Research aim and hypothesis: In this research the researchers aim to develop ways to test changes in practical experience in order to assess unintentional learning related to classic psychomotor skills in engineering technology laboratory classes. In other words, the researchers wish to develop ways to measure the experiential and "hands-on" component of learning that take place in laboratory classes. Therefore, the researchers propose to test the following hypothesis:

- H_1: The change in practical experience in engineering students (level of study gender psychomotor) measured in the context of fault diagnosis resulting from a structured sequence of laboratory classes is statistically insignificant

If the researchers can prove that the hypothesis is false with a high degree of probability, then the researchers can be confident that laboratory classes influence practical experience in the context of diagnosing faults in the relevant equipment and that this change in practical experience (i.e., psychomotor domain) can be measured and assessed. The measuring instruments would then provide a powerful new means to assess the effectiveness of engineering laboratory classes.

The researchers chose to study introductory laboratory classes in electrical engineering fundamentals (PLT107 Electronics, Universiti Malaysia Perlis). This choice was determined partly by our own interests in robotics and automation and partly because these classes are offered annually providing plenty of opportunities for observation and testing. Approximately, 100 engineering technology students take these classes annually providing potentially large sample sizes for testing and evaluation. The framework for assessing learning in the psychomotor domain is shown in (Razali, 2015).

RESULTS AND DISCUSSION

First prototype of the psychomotor testing instrument: The aim of this instrument is to assess psychomotor domain (domain P1-P4) by measuring some aspects of student's practical knowledge related to the laboratory experiments. The researchers devised an on-line multimedia survey to assess the ability to recognize fault diagnosis resulting from a structured sequence of laboratory classes (based on the domain P1-P4). The electronic survey contains graphics, pictures, sound and videos (Razali, 2015). The researchers require two surveys; a pre-lab psychomotor instrument before attending the laboratory and a post-lab psychomotor instrument after attending the laboratory. The researchers predicted that the students will gain practical experience as a by-product of performing the laboratory class and the researchers can measure this by assessing a restricted range of practical knowledge. After doing the experiments the students will be given the same instrument to measure the level of practical experience they gained after attending the laboratory (Fig. 1).

The researchers expect that the results will show if there is any difference in the level of practical experience among students after attending the laboratory experiments. An example of one item from the psychomotor instrument is shown in Fig. 2. A pilot version of the psychomotor instrument was tested with 25 first year and 18 second year students of robotics engineering technology program students. The response items were chosen such that only one provided the most practical response. Participants merely selected what they thought was the most appropriate response item. The mean scores of the psychomotor domain inventory are contained in Table 2. The researchers performed a uni-variate Analysis of Variance (ANOVA) to determine whether there was a difference among the two level of study year 1 and 2 with regard to the psychomotor domain variable. The results demonstrated that the second year students had slightly more practical experience than the first year students.

Table 2: Means, standard deviations, and t-test of psychomotor domain scale

Parameters	Sample	Year 1	Year 2	t-values
P1-perception				
M	2.07	1.83	2.38	
SD	0.72	075	0.06	2.87***
P2-set				
M	3.04	2.95	3.58	2.69***
SD	0.74	0.80	0.695	
P3-guided response				
M	3.48	3.25	3.90	2.02*
SD	0.77	0.74	0.75	
P4-Mechanism				
M	1.77	1.56	1.96	
SD	0.66	0.62	0.72	2.16*

*p<0.05; ***p<0.001

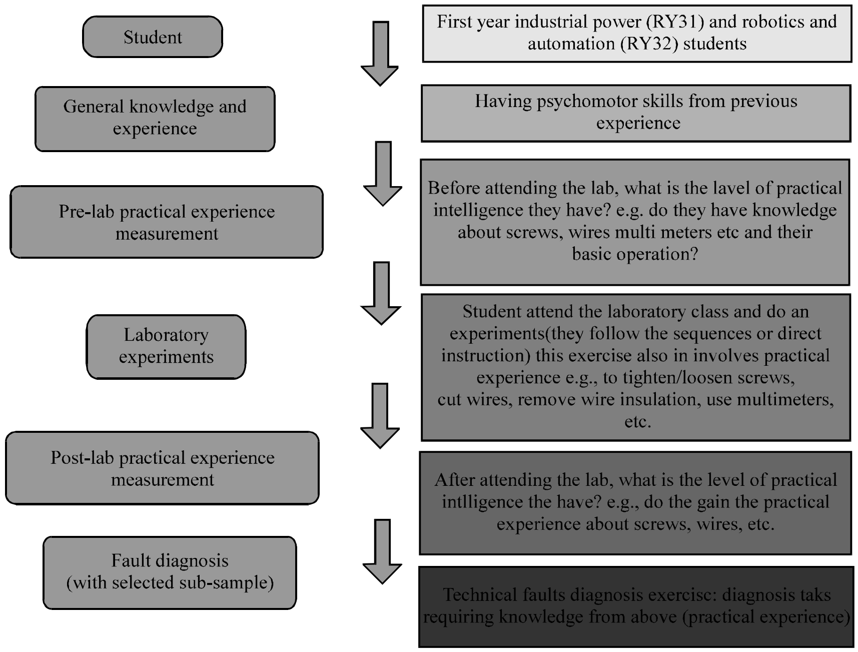

Fig. 1: Framework of assessing psychomotor domain

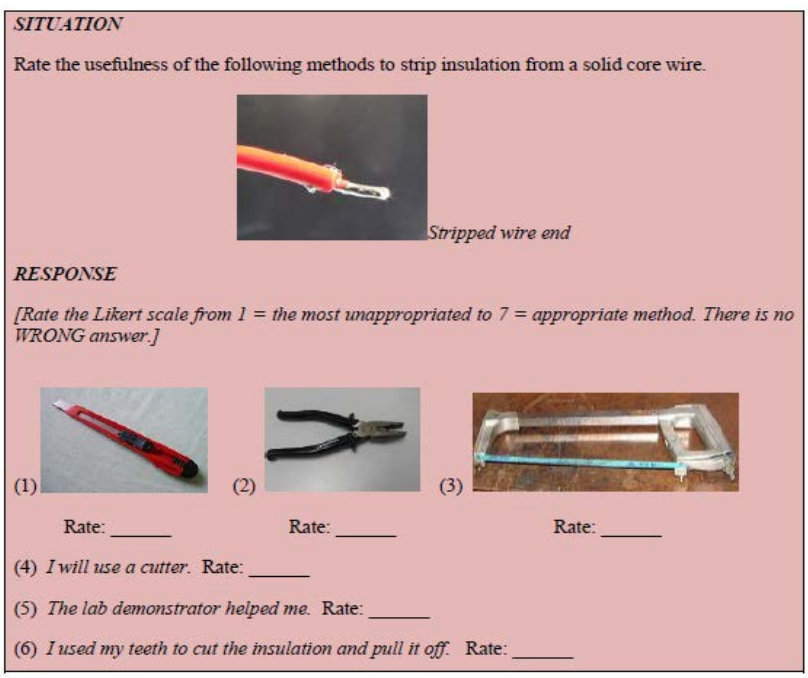

Fig. 2: One item of psychomotor instrument

The researchers used a t-test to analyze the effect of gender on psychomotor domain. Results indicated no differences between male and female students in psychomotor domain scores in most cases (3 of 4 items; $p>0.05$). The researchers also used a t-test to analyze the effect of level of study on psychomotor domain. Level of study year 2 vs 1 was determined by a median score of the corresponding items in the questionnaire. Table 2 shows psychomotor domain mean scores of year 1 students compared with year 2 students. Results showed

Table 3: Results of three-way analysis of variance on laboratory achievement

Source of variance	Mean square	df	F-value	p-value
Level of study	4.96	1	0.22	0.560
Gender	196.09	1	7.18	0.005
Psychomotor domain	37.66	1	4.99	0.030
Level of study X Gender	15.48	1	0.68	0.040
Level of study X Psychomotor domain	2.24	1	0.11	0.740
Gender X Psychomotor domain	104.06	1	4.15	0.030
Level of study X Gender X Psycho. domain	56.59	1	2.64	0.110
Error	3846.9	199		

*,***p<0.05; 0.0011

that in 3 of 4 items of psychomotor domain, the mean scores of the year 2 group were significantly higher than the mean scores of the year 1 group. In addition, the mean scores of the overall inventory were higher for the students with Year-2 than for the students of year 1.

The researchers performed a three-way ANOVA to test the effects of psychomotor domain, gender and level of study on laboratory achievement (Table 3). Its results demonstrated two main effects: psychomotor domain and gender as well as an interaction effect ($p<0.05$). Students with high psychomotor domain achieved significantly higher laboratory grades than those with low psychomotor domain and female students outperformed male students. The findings of the interaction indicated a significant effect of psychomotor domain and gender on laboratory achievement. Male students with high psychomotor domain scores achieved significantly better academic grades than male students with low psychomotor domain scores; no such differences were observed in the female sample. In summary, the researchers examined the effects of two factors, gender and level of study, on the acquisition of psychomotor domain in laboratory experience and its influence on laboratory achievement. Our main findings were that level of study (amount number of attending laboratory classes) affected the acquisition of psychomotor domain and the interaction between gender and psychomotor domain affected laboratory achievement.

However, based on the results, several of the participants omitted responses (suggesting that they did not understand questions) and the researchers realized that there were multiple interpretations of some of the response items. This study confirmed findings in the literature discussed above that response items require rating scales so that participants can rate the appropriateness of each item. This study also confirmed the need for careful and patient observation of actual student behaviour during the experiments and the need to conduct semi-structured interviews with the students after they have completed the required tasks.

On the assumption that this larger scale study will confirm that our hypothesis is false, that there is a statistically significant difference in practical experience of students measured (in the psychomotor domain) before and after exposure to the laboratory class experience, the researchers will proceed to the confirmation stage of this study. The researchers will select a sub-sample of survey respondents and invite them to participate in a practical fault diagnosis task on some of the equipment that they will have used in their laboratory classes. If possible, the researchers will select two sub-samples: a sample of students with high levels of practical experience as measured by our survey instrument and a sample of students with low levels of practical experience.

From this study the researchers know that there is a very large variation in student responses even after they have completed their laboratory experience. These selected students will be observed performing a small number of troubleshooting tasks and their performance will be evaluated. The researchers expect that this study will provide rich qualitative data which can be used to provide triangulation support for psychomotor domain measurement through a online instrument. The researchers would expect that practical experience measured in the context of diagnosing simple faults in the circuits used for the laboratory experiments will be correlated with performance in real troubleshooting tasks on the same circuits.

CONCLUSION

The researchers examined the effects of two factors, gender and level of study, on the acquisition of psychomotor domain in laboratory experience and its influence on laboratory achievement. The main findings were that level of study (amount number of attending laboratory classes) affected the acquisition of psychomotor domain and the interaction between gender and psychomotor domain affected laboratory achievement. It is possible that, the researchers may be able to alter student learning behaviour by including psychomotor domain tests in assessment processes. It is well known that assessment practice drives student learning behavior. The testing may motivate students to acquire the ability to learn practical experience which could ultimately make them more effective as practicing engineers. It is possible that they will learn to value the practical experience and possibly relate better to tradespeople and technicians on whom engineers need to rely to achieve practical results from their work. The results demonstrate that the researchers can devise effective ways to measure their psychomotor domain on practical experience acquired by students from laboratory experiences. This would provide a third means to evaluate engineering technology laboratory class experiences, beyond the established methods of comparing student performance in explicit assessment tasks, (e.g., reports, tests) and measurement of student perceptions of their laboratory experience. With the availability of the assessment method for psychomotor domain (hands on skills), stakeholders can be more confident of hands-on competencies of engineers and engineering technologist who are the key players in the future development of our nation.

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