

## Assessing Engineering Students' Practical Intelligence as the Outcome of Performing 'hands-on' Laboratory Classes

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### Abstract

Experience in an engineering laboratory is important for engineering students and expected to enhance understanding of engineering concepts for which they have learned the theory. Although the aim of the laboratory is an opportunity to learn and gain experience or practical intelligence (PI), the authors do not know much about what actually happens in a typical laboratory class. The development of practical intelligence is expected to be happened when students are performing tasks in the laboratory exercises and they may possibly be able to detect and solve problems or diagnose faults in similar equipment. Thus the purpose of this study is to assess students' practical intelligence as the outcome of performing laboratory exercises and relating to the ability to diagnose equipment faults. Comparison of novel-expert rating approach is used in this study. The findings demonstrated that practical intelligence can be measured by calculating the difference between students' ratings and the experts' ratings.

*Keywords:* Experience; practical intelligence; unintentional learning; hands-on; engineering laboratory

### Abstrak

Pengalaman dalam makmal kejuruteraan adalah penting bagi pelajar kejuruteraan dan dijangka dapat meningkatkan kefahaman konsep kejuruteraan yang mana mereka telah mempelajari teori. Walaupun tujuan makmal merupakan peluang untuk belajar dan memperolehi pengalaman atau kepintaran praktikal (PI), penyelidik tidak mengetahui dengan mendalam apa yang sebenarnya berlaku di dalam makmal. Perkembangan kepintaran praktikal dijangka berlaku apabila pelajar melaksanakan ujikaji di dalam makmal dan mereka berkemungkinan mampu mengesan dan menyelesaikan masalah ataupun mengdignosa kesilapan bagi peralatan yang serupa. Oleh itu tujuan kajian ini adalah untuk menilai kepintaran praktikal pelajar sebagai hasil pelaksanaan ujikaji makmal dan kaitannya dengan kemampuan untuk mengdignosa kesilapan peralatan. Kaedah perbandingan perkadaran pakar-pemula digunakan dalam kajian ini. Dapatan kajian menunjukkan kepintaran praktikal boleh diukur secara pengiraan perbezaan di antara perkadaran pelajar dan pakar.

*Kata kunci:* Pengalaman; kepintaran praktikal; pembelajaran tanpa niat; kerja tangan; makmal kejuruteraan

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## 1.0 INTRODUCTION

### 1.1 Experience and Engineering Laboratory

Engineers seek to manipulate material and energy for the benefit of humankind. This task will successfully be achieved if the engineers, technicians and others have knowledge and experience related to the specific engineering field. Therefore, at university or college level, engineering education helps students gain the foundation for acquiring knowledge and experience that will help them in engineering practice.

Experience in an engineering laboratory is playing an important role for engineering students (Feisal & Rosa, 2005). By attending laboratory classes and handling (working with) the

equipment, the students are likely to appreciate more details about the appearance and function of the laboratory. Evaluations suggest that these laboratory experiences are just as likely to enhance understanding of related concepts for which students have learned theory (Lindsay & Good, 2005). Although the aim of the laboratory is giving opportunities for students to learn and understand engineering concepts, the authors do not know what actually happens in a typical laboratory class.

It is accepted that practical know-how is essential for high achievement in the workplace (Somet & Ronet, 1999; Wagner & Sternberg, 1985). Furthermore, Sternberg Wagner (1993) proposed that this type of know-how or what they have called '*practical intelligence*' is closely related to what Polanyi (1996) has called '*tacit knowledge*', which it is not openly expressed or stated, and it

usually is not taught directly. Practical intelligence is *the ability of a person to solve practical issues in a given domain, typically measured with a practical intelligence inventory (a survey instrument or questionnaire which consists of situations associated with many responses)*.

Through their laboratory experience, the authors expect that students may acquire practical intelligence. 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 develops either intentionally or unintentionally and the authors hypothesize that unintentional learning is an important aspect of laboratory work (Christiansen & Rump, 2007). Unintentional learning is *knowledge gained by experience without the intention to learn anything*. For this reason, the authors define ‘unintentional learning’ as the process by which practical intelligence is acquired in laboratory classes, outside and beyond the stated learning objectives.

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 (Lindsay & Good, 2005), the authors 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 which might allow them to diagnose the faults of equipment. Therefore, in this study, the authors examine unintentional learning through experience of laboratory work and the subsequent ability to diagnose equipment faults.

## 1.2 Objective and Hypothesis

In this research the authors aim to develop ways to test changes in practical intelligence in order to assess unintentional learning classic implicit knowledge in engineering laboratory classes. In other words, the authors wish to develop ways to measure the experiential and “hands-on” component of learning laboratory classes. Troubleshooting and diagnosing faults in equipment has been suggested as a task that requires a high degree of practical intelligence and tacit knowledge. Therefore, the authors propose to test the following hypothesis:

*H1: The change in practical intelligence in engineering students measured in the context of experience from a structured sequence of laboratory classes is statistically insignificant.”*

If the authors can prove that the hypothesis is false with a high degree of probability, then the authors can be confident that laboratory classes influence practical intelligence, and that this change in practical intelligence can be measured and assessed. The measuring instruments would then provide a powerful new means to assess the effectiveness of engineering laboratory classes and also to measure differences between hands-on, simulation and remote laboratories.

## 2.0 LITERATURE REVIEW

### 2.1 Experience or Practical Intelligence

The concept of unintentional knowledge is closely related to the concept of skills, used mostly to describe practical know-how (Wagner, 1987) and is gained through practical experience in various contexts. For instance, Sternberg *et al.* (1995) explored implicit knowledge in academia as practical intelligence, and they insisted that in order to succeed in academia, a person needs expert

knowledge in the domain. In the daily environment, many problems are tackled by using practical intelligence, which emphasizes procedures or “knowing how,” but for a formal academic environment, academic knowledge is considered as “knowing what”. Sternberg (1995) describes practical intelligence as “*a person's ability to apply the components of intelligence to everyday life*”. It is based on procedural information relevant to one's daily life.

Practical intelligence seems to be acquired through experience. Kolb (1984) provides four stages of experiential learning: i) active experimentation, ii) concrete experience, iii) reflective observation and iv) abstract conceptualization. Ideally all these should be incorporated in the practical exercise. Hence the authors could predict that through learning-by-doing processes, the students will develop their critical thinking and awareness of the equipment faults in their working environment. However, in practice, many laboratory classes have no clearly defined learning objectives and those that do often provide objectives that cannot be readily assessed (Feisel & Rosa, 2007) and most display relatively scant attention to pedagogy. Therefore, one can argue that while there is *potential* for structured experiential learning, the absence of design suggests that acquisition of practical intelligence will be a by-product of laboratory class experiences rather than an intentional outcome.

For example, in one of our survey questions, students are asked why the authors do not tighten a nut too hard. The knowledge for this question is likely to have been learned without direct instruction but develops through observation, ‘trial-and-error’ experience, and mistakes.

### 2.2 Experiences in Laboratory Classes

One of the most important factors in forming engineering graduate qualities is the practical component of the engineering curriculum (Feisel & Rosa, 2007). 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 to operate tools and equipment safely. Webb (2003) wrote that the underlying reason for the value of laboratory classes are that they provide a fundamentally different context for the students’ learning. In a laboratory class, their environment is different compared to other learning modes, such as 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.

### 2.3 Testing Practical Intelligence

Researchers have shown that tacit knowledge in the form of practical intelligence can be effectively measured (Razali & Trevelyan, 2007, 2008). Psychologists have debated the merit of tacit knowledge 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 (Schmit & 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 intelligence and tacit knowledge measurement argue that personality tests in combination with practical intelligence

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 ability to comprehend the questions correctly. Testing practical intelligence is still not widely accepted as a recruitment selection tool.

In our situation, however, researchers are not attempting to make forward predictions on the basis of practical intelligence measurement. The authors only wish to measure the acquisition of practical intelligence in a relatively constrained situation, a sequence of planned laboratory experiments.

### 3.0 METHODOLOGY

#### 3.1 Research Medium

Before deciding to choose a research medium, the researcher had to identify the learning outcomes (explicit and implicit/tacit) from laboratory classes. Is it possible that PI could be acquired by attending and performing the laboratory tasks? Based on some discussions with lecturers and technicians, the researcher deduced that PI can be explored in electronics laboratory classes in which students construct and test basic electronic circuits.

#### 3.2 Research Design

The focus of this study is to investigate the contribution of a treatment (laboratory class) to a dependent variable—the PI score for each participant. This is the primary factor (performing tasks in the scheduled laboratory class) to be investigated. Therefore the researcher has to see how the factor influences the outcomes using the proposed research design.

Figure 1 shows the suggestion of the “*pre-test and post-test control group design*”. The symbol in Figure 1 that represents the pre-test is  $X$  value and the post-test is  $Y$  value, providing four group means (subscript  $E$  for treatment,  $C$  for control).

Figure 1 Pre-test and post-test control group design

Independent group	Pre-test	Treatment	Post-test
With laboratory session (Treatment)	$X_E$	Laboratory class	$Y_E$
Without laboratory session (Control)	$X_C$	(no treatment)	$Y_C$

#### 3.3 Samples and Procedure

The first step in this study was to observe the behavior of students in the laboratory classes. The sample for this step consisted of 20 randomly selected students who enrolled in the Introduction to Electronics class. The authors observed the students individually during the experiments and interviewed them informally after they had completed their assigned tasks. Through the observations and interviews, the authors predicted that the students would gain unintentional experience and knowledge when they were doing the experiments.

For example, one of the instructions students had to follow was to strip both ends of a green wire. First they had to cut the wire in half, one half for an antenna and the other for a ground connection. The students could request pliers from lab demonstrators because they were not provided in the first instance. The author noticed that some of the students used their creativity to strip ends of wires; they used a cutter to cut around the insulation and pull it off.

One of the students used an alligator clip to pierce the insulation and tried to pull it off. Other students used their teeth to cut and pull off the insulation. Some of the students were able to use pliers to strip both ends of the wires. Many students asked lab demonstrators to show them how to do that. (The authors noted that the laboratory supervisor had perhaps overlooked providing purpose-designed wire stripping tools).

From the observation, the authors concluded that students may already have relevant practical intelligence. In order to determine the extent of unintentional learning the authors need to assess practical intelligence before and after the laboratory class experience.

#### 3.4 Practical Intelligence Instrument

A typical practical intelligence 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 intelligence 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. Figure 2 shows the example of *situation and responses*.

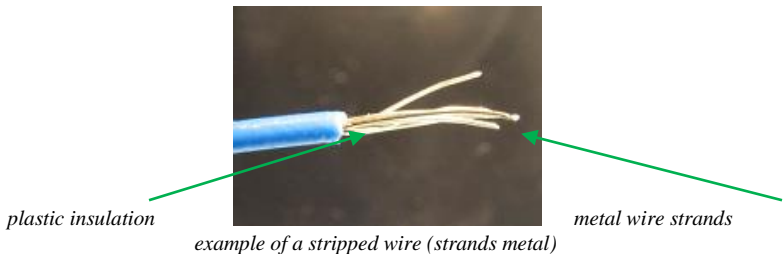
The response items are obtained through semi-structured interviews of experts in the particular domain. Alternatively, if the instrument designer is sufficiently expert, the response items can be generated directly. In some testing instruments the response items are deliberately constructed to be incorrect or distorted application of simple rules of thumb.

In the test instrument, each response item has a rating scale (typically 1=low to 9=high). Participants are asked to rate the importance of each item.

A set of reference scores is obtained by asking a number of experts to provide their ratings and calculating an average rating each item from the experts. After this calibration step, the test is scored by calculating the square of the deviation in the respondent's rating relative to the average scores provided by experts.

**Situation**

One of the instructions to construct the crystal radio set in your experiment:  
*“In the package, there is a long blue wire. Cut it in half. Use one length as antenna and one length as the ground connection. Strip both ends of the blue wire you intend to use as a ground connection. Connect one end to terminal 5 and the other end to a good earth. Then strip one end of blue wire you intend to use as the antenna. Connect it to terminal 1”.*



plastic insulation      metal wire strands  
 example of a stripped wire (strands metal)

After reading the instructions and having the blue wires, you are not sure how to strip the wires. You should find a suitable method to do the task. Please rate the following alternative methods before doing the tasks.

**Responses**

- 1 Watch your friends stripping wires, then follow their methods.
- 2 Follow your friend while they do the tasks.
- 3 Ask your friend to do it for you.
- 4 Read the instructions again, if you misunderstand any part of the instructions.
- 5 Try to do it yourself without asking your friends or lab demonstrators.
- 6 Use any sharp tools on your workbench which can be used to cut the insulation.
- 7 In the middle of doing the tasks show to a lab demonstrator to check your work.
- 8 Ask the lab demonstrator to show you how to strip the wires.
- 9 Request an appropriate tool to strip the wires from the lab demonstrators.
- 10 Think which tool would be appropriate to strip the wires.

Figure 2 Example of situation and responses

### 3.5 Behavior of Practical Intelligence

During the experiments, the students had to follow the sequences or direct instruction in the experiment handout presented as explicit knowledge. At the same time, without necessarily realizing, they had to use their practical intelligence. Figure 3 (next page) shows an example of the practical intelligence involved in the task of stripping the wire ends.

However several of the participants omitted responses (suggesting that they did not understand questions) and the authors 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.

## 4.0 RESULTS AND DISCUSSION

### 4.1 Pilot Study

A pilot version of the online survey instrument was tested with 25 second year mechanical engineering students and 18 postgraduate 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.

For this pilot test, there are 4 independent variables involved: previous experience (Exp), apprenticeship program attended (Appr), interest in laboratory work (Int) and have own workshop at home (Wks). Table 1 shows that for postgraduate, the previous experience (Exp) as an independent variable plays a significant role in the achievement in the survey, whereas other variables didn't show any significant value. The similar result obtained for undergraduate. Furthermore, the other results also demonstrated that the postgraduate students had more practical intelligence than the second year students.

Table 1 Summary of analysis

Residuals:				
Min	1Q	Median	3Q	Max
-4.5718	-1.4945	-0.5718	2.0221	5.4282
Coefficients:				
	Estimate	Std. Error	t value	Pr(> t )
(Intercept)	4.6667	1.6758	2.785	0.0111 *
Exp Yes	7.2155	1.4948	4.827	9.02e-05 ***
Appr Yes	-0.4061	1.4065	-0.289	0.7756
Int Yes	-2.9042	2.1932	-1.324	0.1997
Wks Yes	-1.7624	3.2290	-0.546	0.5910

Sign if. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
 Residual standard error: 2.903 on 21 degrees of freedom  
 Multiple R-Squared: 0.6032, Adjusted R-squared: 0.5276  
 F-statistic: 7.981 on 4 and 21 DF, p-value: 0.0004471

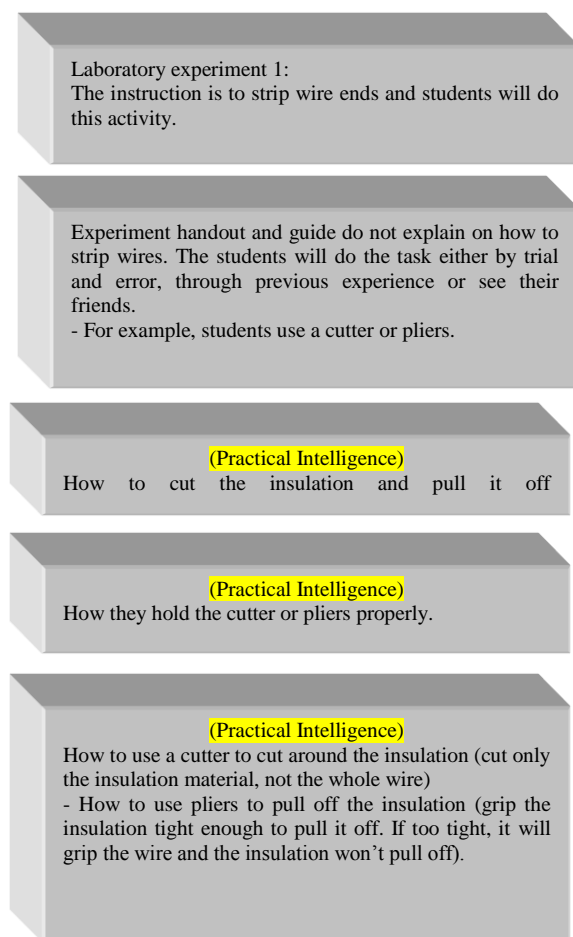


Figure 3 Practical intelligence involved in the stripping task

Table 2 Results of practical intelligence test

No	Analyses	Mean of PI test ( experts' mean = 324)	Std. Deviation	Sig. (2 tailed)
1	Pre-test	259.75	35.34	p = 0.078
	(treatment vs. control)	195.31	36.15	
2	Treatment group	210.73	35.34	p = 0.000**
	(pre-test vs. post-test)	259.75	18.95	
3	Control group	195.31	36.15	p = 0.076
	(pre-test vs. post-test)	204.68	33.80	
4	Post-test	259.75	18.95	p = 0.000**
	(treatment vs. control)	204.68	33.80	

\*\* Significant at the 0.01 level (2-tailed)

1. There is no significant difference ( $p = 0.078 > 0.05$ ) in initial practical intelligence between the treatment and control groups. Both groups have the same level of initial practical intelligence as indicated by the pre-test scores.

2. For treatment group, there is a significance difference ( $p = 0.000 < 0.05$ ) between the pre-test and post-test scores. There is an increment in the post-test score (mean 259.75) compare to the pre-test score (mean 210.7266). The treatment group is expected to acquire practical intelligence during the lab session. Thus they are able to perform better in the post-test.

3. In contrast, for the control group, there is no significance difference ( $p = 0.076 > 0.05$ ) between the pre-test and the post-test scores. Even though, there is an increment in the post-test score (mean 204.6800) compare to the pre-test score (mean 195.3100), the difference is not statistically significant. The results

This pilot 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. Even though the authors are both experienced teachers, it was sometimes difficult to understand the most simple and basic gaps in their knowledge.

## 4.2 Extended Studies

The researchers were designing a survey instrument to measure practical intelligence related to introductory electrical engineering laboratory exercises which will be used to test a large sample of students. On the assumption that this larger scale study will confirm that our hypothesis is false, that there is a statistically significant difference in practical intelligence of students measured before and after exposure to the laboratory class experience, the authors will proceed to the confirmation stage of this study. The results of this investigation demonstrated that both of the original null hypotheses are false. These results demonstrated that practical intelligence (PI) can be measured by calculating the difference between participants' ratings and the experts' ratings. The detailed results are as follow and summarized in Table 2.

suggest that the intervening course work on other unrelated studies does not contribute toward practical intelligence improvement.

4. The authors also compared the post-test scores for the treatment and control groups. In this analysis, there is a much larger and more significant difference ( $p = 0.000$ ) between the post-test scores for the treatment group (mean 259.75) and the control group (mean 204.68) scores.

## 5.0 CONCLUSIONS

In this paper the authors have attempted to show the possibility of measuring practical intelligence, tacit knowledge and implicit knowledge that has not been assessed or measured in the past when evaluating different laboratory experiences for engineering

students. It is possible that techniques for measuring practical intelligence that have emerged from attempts to improve selection in recruitment processes may provide a way to measure that elusive component of engineering laboratory experiences referred to by most people as "hands-on practical experience". This would provide a third means to evaluate engineering 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.

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