Ability in diagnosing equipment faults: contribution of students' practical intelligence

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ABSTRACT

Industry reports on engineering graduate abilities often point out their lack of practical skills. The concept of practical intelligence has been developed by psychologists seeking to find better ways to evaluate the most suitable applicants for particular jobs in occupations. This research led to psychometric test instruments to measure practical intelligence in a context of laboratory tasks. The authors hypothesised that these developments in psychology could be applied to measure the practical, hands-on component of student learning in engineering laboratory classes. Until now, laboratory classes have only been evaluated by measuring explicit cognitive knowledge reproduced by students in reports and tests and asking students for their rating of the laboratory experience. Practical skills, on the other hand, are rarely mentioned as learning outcomes and the only way of measuring practical skills has been through direct observation. The authors developed a testing instrument appropriate for a first-year electrical engineering laboratory class to measure practical intelligence in the context of simple electronic circuits. Testing on large samples of students has demonstrated that it is possible to measure practical intelligence acquired through laboratory classes. Further testing has demonstrated that these learning outcomes predict the ability to diagnose simple faults in laboratory circuits.

Keywords: *practical intelligence, engineering practice, engineering laboratory classes, faults diagnosis, assessment.*

INTRODUCTION

Hands-on laboratory classes have always been valued for the practical experience gained by engineering and science students, but the value however, has not been so easy to quantify. An effective way to measure practical experience might provide a useful way to compare the learning utility of hands-on laboratory classes with alternatives such as simulations, virtual laboratories and remote access laboratories (Feisel & Rosa, 2005). Currently, in the evaluation of engineering laboratory work, most assessment involves only explicitly specified learning outcomes and usually the element of tacit knowledge, implicit knowledge or practical intelligence has not been assessed or measured. Implicit knowledge viewed as an important aspect of practical intelligence, that is, the ability to use one's intelligence in the day-to-day situations that confront one in everyday life. A major part of the justification for laboratory learning is the "hands-on" experience which can be as valuable an outcome as explicitly stated learning objectives (Sternberg et al. 1995). However, it is not easy to assess the level of practical intelligence that students bring to the laboratory classes and any that they might 'unintentionally' gain through the laboratory experience. Moreover, it is possible they may gain experience sufficient for troubleshooting: to be able to detect and solve problems or diagnose equipment faults.

Practical intelligence can be defined as 'informal learning', and could also be useful learning outcomes from a laboratory experience alongside the explicitly defined outcomes, therefore it can potentially be measured and assessed. Previous study demonstrates that effective ways to measure practical intelligence acquired by engineering students from laboratory experiences can be devised. The question is, do the students who gain experience during their laboratory classes possess a high enough level of practical intelligence through informal learning which might allow them to diagnose equipment faults? (Razali & Trevelyan, 2008c). This further study on equipment fault diagnosis demonstrates the possibility that practical intelligence predicts fault diagnosis ability. Thus, this paper describes an investigation on the effect of practical intelligence through experience of laboratory work and the subsequent ability to diagnose equipment faults. Relevant literature was reviewed to inform this study.

THEORETICAL FRAMEWORK

Practical Intelligence

Empirical studies (Goodnow 1986; Mercer, Margarita et al. 1986; Eraut 2000; Christiansen and Rump 2007; Trevelyan 2007; Trevelyan 2008; Razali & Trevelyan 2008b) have shown the acquisition of practical intelligence in laboratory class is just as important as explicit technical knowledge. Practical intelligence (tacit knowledge, implicit knowledge and skill gained through experience) is often "informal learning" (Razali and Trevelyan 2008c) because it is not often listed as an assessable learning outcome.

Practical intelligence enables action with appropriate results. Practical intelligence develops by performing 'hands-on' experiments or research work in engineering laboratories and many authors have commented on its importance (Scribner 1986; Burford & Gregory 2002) particularly in troubleshooting (e.g. Barely & Bechky 1994; Zucker & Darby 2001; Gorman 2002; Mody 2005). Experienced troubleshooters and technical investigators rely on significant practical intelligence (MacPherson 1988; Johnson, 1989; Flesher 1993; Christiansen & Rump 2007).

Researchers (e.g. Wagner & Sternberg, 1985; Sternberg et al. 1990; Somech & Ronit, 1999; Leornard & Insch, 2005) have shown that practical intelligence can be effectively measured. Psychologists have debated the merit of practical intelligence 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 (Ree & Earles, 1992; Schmidt & Hunter, 1993) argued that practical intelligence is simply the result of on-the-job learning. General intelligence is the best predictor, they argued, of the ability to learn, and fast learners will acquire job-specific knowledge faster. On the other hand, proponents of practical intelligence measurement (Wagner & Sternberg, 1985; Sternberg et al. 1995; Sternberg 2006b; Sternberg 2007) argued 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.

Diagnosing Equipment Faults

There has been extensive research on troubleshooting and fault diagnosis in engineering practice in the last 20 years, especially studies on novice and expert troubleshooters in order to understand their cognitive processes and skills (Johnson, 1989). This and many other similar studies (Flesher, 1993) demonstrated that troubleshooters make extensive use of tacit and implicit knowledge which has to be developed through experience. Moreover, in the diagnosis system, the diagnostic engineer or technical person must have well self-enhancing knowledge of how to relate faults and the implications, which one has to learn from experience. This self-enhancing knowledge is developed through their working experience, and either explicit or tacit, but is expected mostly practical intelligence. By utilizing this knowledge, they will be expected to provide information of diagnostics for failure localization, planned preventive maintenance and service staff. This is a powerful argument in support of the need for engineering students to practice and value the acquisition of practical intelligence.

Furthermore, experienced engineers have told us that engineering graduates do not seem to be aware of the kinds of practical intelligence needed in their work (Trevelyan 2007; Trevelyan 2008). This may result from the way in which explicit knowledge is valued in engineering education: practically all assessments measure explicit knowledge. This implicit devaluation of practical intelligence might significantly impair engineering students' ability to acquire and value practical intelligence. Therefore developing ways to include effective assessment could be one way to overcome this difficulty.

Measuring Practical Intelligence

Practical intelligence could also be a useful learning outcome from a laboratory experience. Nonetheless, when evaluating engineering laboratory work, practical intelligence has not been assessed or measured. It is not easy to assess the level of practical intelligence that students bring to the laboratory classes and the additional component that they might gain from the experience. Typically laboratory classes have been evaluated by assessing explicit specified learning outcomes and student perceptions of their laboratory experience. Specified learning outcomes are typically in the form of propositional knowledge related to cognitive learning outcomes for the associated lecture and tutorial classes.

The authors have not been able to find any research undertaken to measure practical intelligence acquired during laboratory work. Developing effective assessment tools to measure practical intelligence, could be one way to value the hands-on component of laboratory classes. Workshop skills have been traditionally assessed by observing students performing their work and the quality of the artifacts created in the process. Practical intelligence is a critical part of these skills. Workshop skill courses formed a significant part of engineering education but were displaced by mathematical and science-based courses in the 1950s and 1960s.

In this article, the authors are interested, in particular, in measuring the acquisition of practical intelligence in a relatively constrained situation, a sequence of planned laboratory experiments. The authors demonstrated that experience developed either intentionally or unintentionally as a result of performing laboratory tasks, and students acquired explicit knowledge and practical intelligence concurrently. A study with an on-line practical intelligence survey instrument has demonstrated that first year electrical engineering student's gain significant practical intelligence from laboratory class experiences when compared with a control group. A further study showed that practical intelligence predicts students' ability to diagnose faults in related equipment.

Tacit Knowledge as Theoretical Framework

Sternberg and his colleagues (Sternberg & Wagner, 1986; Sternberg et al., 1995; Wagner & Sternberg, 1985) have taken a knowledge-based approach to understanding practical intelligence. Individuals draw on a broad base of knowledge in solving practical problems, some of which is acquired through formal training and some of which is derived from personal experience. Some of the knowledge associated with successful problem solving can be characterized as tacit (Polanyi, 1966). It is knowledge that typically is not openly expressed or stated. It is acquired largely through personal experience and guides action without being readily articulated.

The term *tacit knowledge* has roots in works on the philosophy of science(Polanyi, 1966), ecological psychology (Neisser, 1976), and organizational behaviour (Schoon, 1983), and has been used to characterize the knowledge gained from everyday experience that has an implicit, unarticulated quality. Such notions about the tacit quality of the knowledge associated with everyday problem solving also are reflected in the common language of the workplace as people attribute successful performance to "learning by doing" and to "professional intuition" or "instinct" (Eraut, 2000). Further, Sternberg and his colleagues (Sternberg et al, 2000; Wagner & Sternberg, 1985) view tacit knowledge as an important aspect of "practical intelligence" that enables individuals to adapt to, select, and shape real-world environments. It is knowledge that reflects the practical ability to learn from experience and to apply that knowledge in pursuit of personally valued goals.

Research by Sternberg and his colleagues (Sternberg et al., 2000; Sternberg & Wagner, 1993; Sternberg et al., 1995) has shown that tacit knowledge has relevance for understanding successful performance in a variety of domains; in our case, in engineering laboratory setting. They used novices-experts approach in constructing their instrument. They asked experts to share their experiences of their most remarkable professional achievement as well as their most remarkable professional failure, for the purpose of identifying representative work-related situations in which practical intelligence was important. They interviewed the experts and also asked to describe alternative ways of solving the problems they had confronted. On novices' side, they compared the experience of novices by asking novices to describe how they handled the incident, 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. On the basis of these interviews, a set of practical intelligence testing instrument (in the relevant contexts) was constructed that required subjects to make judgment and decisions.

METHODOLOGY

Research aim and hypotheses

The aim of this research is to find ways to measure changes in practical intelligence in engineering laboratory classes. The authors would also like to test the relationship between practical intelligence acquired in laboratory classes with the ability to diagnose simple equipment faults in laboratory arrangements.

The authors propose a null 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 this hypothesis is proved to be false, the authors can conclude that the authors can detect the acquisition of practical intelligence during the laboratory exercises. The results may also show if there is any difference in the level of practical intelligence among students before and after performing a single laboratory exercise.

The authors also propose a second null hypothesis that: there is no significant correlation between practical intelligence acquired in laboratory experiments with the performance in troubleshooting tasks on similar equipment. If this hypothesis is also proved to be false, the authors can conclude that there is a relationship between the levels of practical intelligence gained by performing the laboratory tasks with the ability to diagnose equipment faults.

Population and Sample

The authors developed an on-line survey instrument to measure practical intelligence in the context of laboratory classes that support the unit Introduction to Electrical and Electronics Engineering (GENG1002). This unit is one of eight units in the first year of the engineering course. Students can take the unit in their first or second semester. This instrument was used to test a large sample of students in the second half of 2008. The unit is compulsory for all the 700 first year students commencing engineering each year at The University of Western Australia (UWA). The aim of this survey instrument was to assess practical intelligence by measuring some aspects of students' practical knowledge related to the laboratory experiments.

A typical practical intelligence survey instrument consists of a set of domain-related situations, each with between 8 and 20 response items. Each situation poses a problem for a participant to solve. Each response item describes a solution approach or action in words. Each participant rates the appropriateness of the alternative response items, typically on a 7 point Lickert scale. Recognized domain experts also take the survey instrument to establish a reference mean score and variance for every response item. On some items the experts will agree closely with each other. On others the experts may differ significantly. The participant's score is then calculated by finding the deviation between the participant's score for each response item and the mean of the expert ratings. The deviation is compensated by the variance between experts so that if the experts disagree on a particular response item, the participant's deviation is less significant. A zero score, therefore, indicates perfect agreement with expert ratings.

To construct the survey instrument, the authors started by observing students individually during their laboratory experiments and interviewed them informally after they had completed their assigned tasks. Through these early observations and interviews, the authors predicted the kinds of practical experience that students would acquire while they were performing the tasks. Then the authors designed an on-line survey instrument which describes a number of situations, problems or fault conditions in which practical intelligence will be needed. For each situation or problems, the survey provides between 10 and 20 possible response items, each of which describes one possible method to solve the problem or execute the task.

The survey instrument was used to test a large number of students (n=139) before and after they performed the relevant laboratory experiment tasks (the treatment group). The pre-test and post-test surveys contained the same problems and response items. However, the order of problems and the order of the response items were changed for the post-test. A control group (n=100) was recruited from a similar population of first year students who were due to enrol in the same unit in the following semester. The control group completed the pre-test and post-test surveys twice with a similar elapsed time between exposures, but without completing the laboratory task. Seven domain experts such as laboratory demonstrators and electronics technicians provided reference scores as mentioned above. The sample group and control groups were both offered the opportunity to take part in a random draw for AUD500 as an incentive to complete both surveys.

Practical intelligence testing instrument

As example, in one of the test items: "In one of lab experiments, you have learnt to use a multimeter to measure any part of your circuit. After constructing a simple circuit on a prototyping board as circuit diagram below (Figure 1), you are requested to measure voltage across the resistor 4.7 kΩ. You expect to get the value **1.6** but the value **0.5** appears in the multimeter".

The participants were asked to rate the appropriateness of the following methods to detect the mistake (examples of the response items in Figure 2). Unlike previous survey instruments mentioned in the literature, most of the response items consisted of texts and small illustrations to reduce issues with language comprehension. The authors have found that it is not easy to comprehend the basic level of knowledge (or lack of it) faced by students, including knowledge of common technical terms.

Fault diagnosis and repair skills test

In the final phase of this research, the authors invited survey participants to participate in a simple fault diagnosis/repair task on a simple circuit, similar to the one they had used in their laboratory experiment. There were 15 participants who had completed the practical intelligence tests participated in this study: 10 participants from the treatment group and 5 from the control group. These participants were observed performing a diagnose/repair task and their performance was evaluated by a single domain expert. Each participant was required to diagnose and repair the faults with a time limit of 20 minutes. Their performance was scored by observing how many of the faults were diagnosed and repaired, 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).

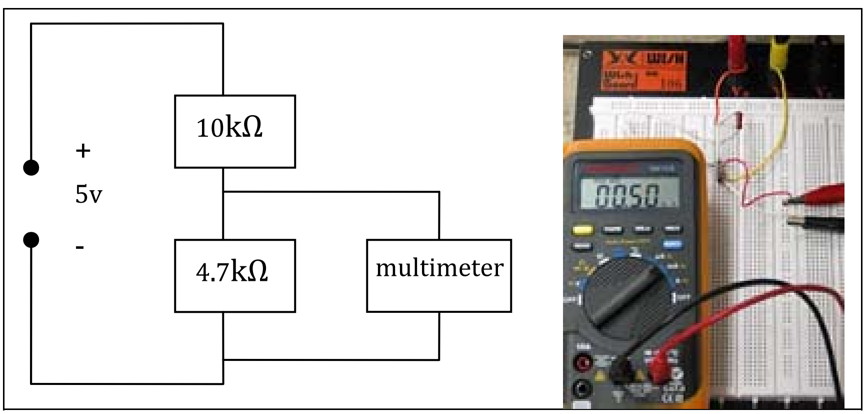


Figure 1: cross section drawing.

The fault diagnosis test consisted of a partially completed circuit in which a battery provides power for a flash light. Although it seems very simple, almost trivial, it was necessary to design a task for which the students' scores would provide sufficient variation to provide statistically meaningful results. A substantially more challenging task may have resulted in performance being more related to random chance than acquired practical intelligence. The test kit is a semi-completed circuit which requires students to diagnose why the light does not work and complete the necessary connections.

RESULTS AND DISCUSSIONS

The results of this investigation demonstrated that both of the original null hypotheses were 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:

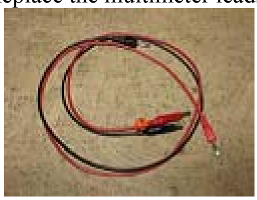
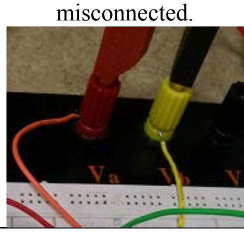
Check the connections between the multimeter leads and the testing points.	Replace the multimeter.
Replace the multimeter leads. 	Check whether you connect one end of the power supply wire to 0V terminal or ground terminal. 
The resistor wire is plugged into the wrong row of holes	Remove all the wires and then construct a circuit again by following the instructions more carefully.
Check the power supply connections to the circuit. The power supply leads might be misconnected. 	Check the measurement scale selected on the multimeter: could it be volts, milliamps, transistor test, diode test, or ohms? 

Figure 2: Examples of the response items.

Table 1: Results of practical intelligence tests

No	Analyses	Mean (close to experts' mean = 0)	Std. deviation	Sig. (2 tailed)
1	Pre-test (treatment vs. control)	113.3 128.7	35.34 36.15	p = 0.078
2	Treatment group (pre-test vs. post-test)	113.3 68.3	35.34 18.95	p = 0.000**
3	Control group (pre-test vs. post-test)	128.7 119.3	36.15 33.80	p = 0.076
4	Post-test (treatment vs. control)	68.3 119.3	18.95 33.80	p = 0.000**

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

Based on the Table 1 above:

1. Both groups had the same level of initial PI as indicated by the pre-test scores.
2. There is a significant difference for treatment group, with an increment in the post-test close to experts' mean score. Data of standard deviation also shows that the spread of data point tends to be close to the experts' score. The results suggest that, the treatment group is expected to acquire practical intelligence by performing laboratory tasks. Thus they were able to perform better in the post-test.
3. In contrast, for the control group, there is no significance difference between the pre-test and the post-test scores. Even though, there was an increment in the post-test score, the difference is not statistically significant. The results suggest that the intervening course work on other unrelated studies does not contribute toward PI improvement.

While the results of the fault diagnosis test showed a novel relationship between PI and the ability to diagnose equipment faults (Figure 3). The score of the fault diagnosis test is proportional to the practical intelligence score, the higher the practical intelligence score, the higher the fault diagnosis score. Therefore the results suggest that PI scores predict ability to diagnose equipment faults in similar laboratory equipment.

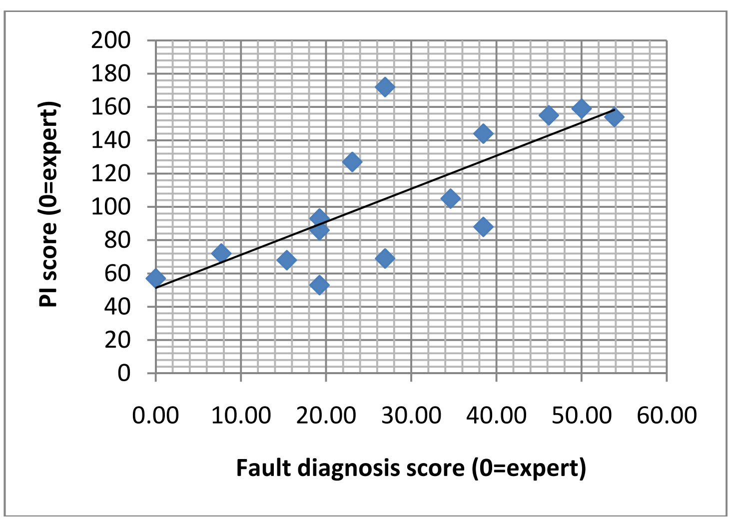


Figure 3: Results of practical intelligence (PI) proportional to fault diagnosis.

CONCLUSION

The results demonstrate that the authors can devise effective ways to measure practical intelligence acquired by engineering students from laboratory experiences. 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. The study on fault diagnosis provided a clear relationship demonstrating the possibility that practical intelligence predicts fault diagnosis ability.

Constructing a survey instrument was not an easy exercise. Both authors were surprised by the relative lack of practical knowledge demonstrated by the students and it was not easy to construct a test which would result in meaningful scores. It is possible that the authors may be able to alter student learning behaviour by including practical intelligence tests in assessment processes. It is well known that assessment practice drives student learning behaviour (Gibbs 1988; Gibbs 1995). The testing may motivate students to acquire the ability to learn practical intelligence which could ultimately make them more effective as practicing engineers. It is possible that they will learn to value the practical intelligence and possibly relate better to tradespeople and technicians on whom engineers need to rely to achieve practical results from their work.

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