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An evaluation of students' practical intelligence and ability to diagnose equipment faults

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Abstract

Empirical studies suggest that practical intelligence acquired in engineering laboratories is valuable in engineering practice and could also be a useful learning outcome from a laboratory experience. Acquiring practical intelligence either intentionally or unintentionally may play an important role in laboratory work and it occurs when the students are performing tasks the laboratory. When evaluating laboratory exercises, previous research demonstrates that students achieve specified explicit learning objectives to varying degrees. Nonetheless, practical intelligence has not yet been assessed or measured. Furthermore, since engineering practice also relies on substantial practical intelligence, it would be useful to study the extent to which students acquire this. One way to assess this is to see how readily students can solve practical problems such as diagnosing faults in the laboratory experiment. Therefore, the aim of this research is to find ways to measure changes in practical intelligence in order to assess informal learning in engineering laboratory classes. We would also like to test the relationship between practical intelligence acquired in laboratory classes with the ability to diagnose simple experiment faults in laboratory arrangements. A methodology of evaluating practical intelligence and assessment of faults diagnosis tasks are described and the results of this study are discussed.

Keywords: practical intelligence, engineering practice, engineering laboratories, faults diagnosis, assessment

1. Introduction

One of the most important factors in forming engineering graduate qualities is the practical component of the engineering curriculum [1] such as laboratory class. Laboratory classes are valuable learning experiences, which can be used to effectively teach the link between theory and real-world behaviour of engineering systems and materials. Work in an 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 [1]. The value of hands-on laboratory classes, however, has not been so easy to quantify. Virtual laboratories, simulation, and remote access laboratories offer alternatives from which students seem to learn as well or better. Although the main aim of laboratory work is to provide opportunities to learn and gain experience, we understand relatively little about what actually happens in a typical hands-on laboratory class.

2. Theoretical basis

2.1 Laboratory classes

For engineering students, experience in an engineering laboratory is an important [1]. By attending laboratory classes and handling (working with) the equipment, the students are likely to appreciate more details about its appearance and function. The underlying reason for the value of laboratory classes is that students are 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.

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 or simulated access. Online laboratory classes have been made possible by advancements in software and communication technologies [2]. Evaluations suggest that these laboratory experiences are just as likely to enhance understanding of related concepts for which students have learned theory as traditional hands-on laboratory classes [3], though there are differences in the way that students experience on-line and simulation labs.

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 [4, 5]. Researchers advocating hands-on laboratories think that engineer needs to have contact with the apparatus and laboratories should include the possibility of unexpected data occurring as the result of apparatus problems, noise or uncontrollable real-world variables [5]. 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 [6]. For example, researchers [7] point out that proficiency in the use of basic equipment such as oscilloscopes and signal a generator 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 [7]. 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.

In typical hands-on laboratory classes, students are usually divided into groups of four or five people and they perform single exercise 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. Although the aim of the laboratory is giving opportunities for students to learn and understand engineering concepts, we do not know what actually happens in a typical laboratory class. Further, our current research on engineering practice is revealing that we have few detailed reports on engineering practice [2]. Therefore it is not easy to decide which laboratory experiences contribute towards a foundation for engineering practice. We cannot be sure about what students will miss or gain when we move from hands-on labs to on-line labs or simulations.

2.2 Practical intelligence

It is accepted that practical know-how is essential for high achievement in the workplace [e.g. [8-12]. Sternberg and his colleague [13] proposed that this type of know-how or what they have called '*practical intelligence*' is closely related to what Michael Polanyi [14] has called '*tacit knowledge*', which it is not openly expressed or stated, and it usually is not taught directly. Empirical studies [2, 15-17] 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” [18] 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 [19] particularly in troubleshooting [20-23]. Experienced troubleshooters and technical investigators rely on significant practical intelligence [15, 24-26].

Researchers [8, 10, 11, and 27] 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 [9, 28] argued that practical intelligence are 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 [12, 29-31] 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.

In our situation, however, we are not attempting to make forward predictions on the basis of practical intelligence measurement. We only wish to measure the acquisition of practical intelligence in a relatively constrained situation, a sequence of planned laboratory experiments. We expect that experience will develop either intentionally or unintentionally as a result of performing laboratory tasks, and students will acquire explicit knowledge and practical intelligence concurrently.

2.3 *Practical intelligence acquired through laboratory experience*

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 intelligence 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. In engineering practice, 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.

Through laboratory experience, we 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 we hypothesize that informal learning is an important aspect of laboratory work [15]. 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 [3], we 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 practical intelligence gained through informal learning which might allow them to diagnose the faults of equipment. Therefore, in this study, we examine informal learning through experience of laboratory work and the subsequent ability to diagnose equipment faults.

2.4 *Diagnosing equipment faults*

There has been extensive research on 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 [32]. According to Gobet [33], fault diagnosis is simply the process of finding the best solution that allows movement from the present state to the goal state. Morris and Rouse [34] stated that fault diagnosis is a special category of problem solving and indicate that when a system is not functioning properly, the troubleshooter must attempt to locate the reason for the malfunction and then must repair or replace the faulty component. According to them, three skill sets are essential to diagnose technical equipment faults: a) the ability to test, b) the ability to replace or repair faulty components, and c) the ability to employ some kind of strategy in searching for the source of the fault. This is congruent with [35] who indicated that the key component of the problem solving process was the ability to recognize and select the most efficient solution path from among all possible solution paths and concluded that identifying and employing an effective strategy was the most difficult skill set for troubleshooters to develop.

This and many other similar studies [24] demonstrated that troubleshooters make extensive use of tacit and implicit knowledge which has to be developed through experience. This is a powerful argument in support of the need for engineering students to practice and value the acquisition of practical intelligence. However, before we can achieve this goal, and given the well-known influence of assessment practices on student learning, we need to develop reliable ways to measure and assess the acquisition of practical intelligence. Psychologists, as shown above, have provided the required methods. All that remains is to develop specific testing instruments in the context of fault diagnosis.

2.5 *Motivation of this research*

We 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 [19], 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.

Experienced engineers have told us that engineering graduates do not seem to be aware of the kinds of practical intelligence needed in their work [2, 36]. 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.

3. Research Question and Hypotheses

The aim of this research is to find ways to measure changes in practical intelligence in engineering laboratory classes. We 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.

We 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, we can conclude that we 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.

We also propose a second null hypothesis: that there is no significant correlation between practical intelligence acquired in laboratory experiments with the performance in diagnosing tasks on similar equipment. If this hypothesis is also proved to be false, we 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.

4. Methodology

4.1 Testing practical intelligence

We 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 [18] in the second half of 2008. The unit is compulsory for all the 700 first year students commencing engineering each year at UWA. The aim of this on-line 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 5 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, we 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, we predicted the kinds of practical experience that students would acquire while they were performing the tasks. Then we 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 Figure 1 shows a simple example of situation or problem is wire stripping. The respondents were asked to rate the appropriateness of different methods and tools for stripping insulation from wires.

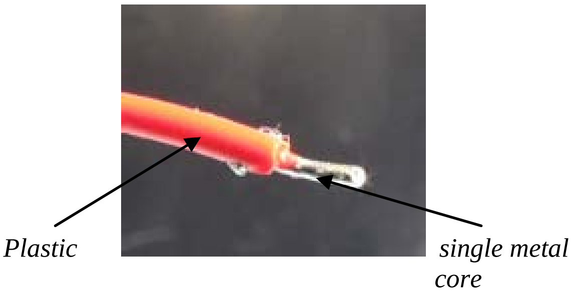

Figure 1: close-up photograph of a piece of connecting wire used in the laboratory tasks.

The response items included different types of pliers, using one's teeth, scissors and several professional wire stripping tools. The Figure 2 shows example of response items. Most of the response items consisted of small illustrations to reduce issues with language comprehension. We 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.

The response items were created as a result of careful observation of both students and experts and included highly appropriate responses and also common inappropriate responses made by students. Respondents rated the appropriateness of each response item on a 7 point Lickert scale. The respondent score was calculated 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 survey instrument was used to test a large number of students (n=139) before and after they performed the relevant laboratory experiment tasks (the experiment 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 enroll 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 an iPod Nano MP3 player as an incentive to complete both surveys.

Figure 2: A selection of images used for response items for wire stripping.

4.2 *Testing on diagnosing equipment faults*

In the final phase of this research, we invited survey respondents to participate in a simple fault diagnosis task on a simple circuit, similar to the one they had used in their laboratory experiment, as shown in figure 3. There were 3 groups of participants who participated in this study. There were two groups who had completed the laboratory tasks, one group with a higher practical intelligence score (n=5) and one group with a lower practical intelligence score (n=5). A control group (n=5) was drawn from the control group for the practical intelligence survey. These participants were observed performing a troubleshooting task and their performance was evaluated by a single domain expert. Each participant was required to diagnose and correct the faults with a time limit of 20 minutes. Their performance was scored by observing 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).

Participants in this study were offered payment of $50 for participation. We needed a significant incentive because the fault diagnosis task could only be arranged when equipment was available, just before the final semester examinations.

The fault diagnosis task 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 Figure 3 shows a photograph of testing kit for the fault diagnosis task. This is a semi-completed circuit which requires students to diagnose why the light does not work and complete the necessary connections.

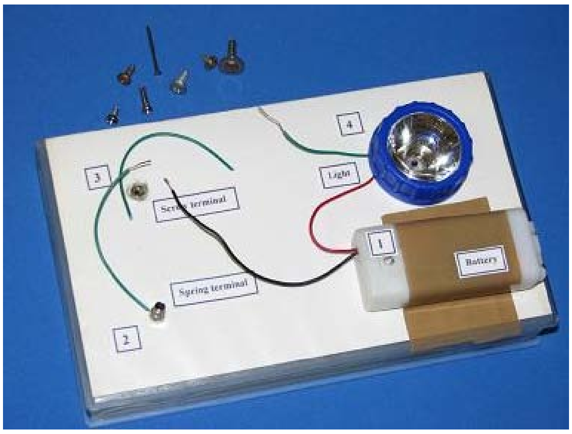

Figure 3: Photograph of fault diagnosis task kit.

5. Results and Discussion

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:

1. There was no significant difference (p = 0.078 > 0.05) in initial PI between the experiment and control groups. Both groups had the same level of initial PI as indicated by the pre-test scores.
2. For experimental group, there was a significance difference (p = 0.000 < 0.05) between the pre-test and post-test scores. There was an increment in the post-test score (mean 255.6906**)** compare to the pre-test score (mean 210.7266). The experimental group was expected to acquire practical intelligence during the lab session. Thus they were able to perform better in the post-test.
3. In contrast, for the control group, there was no significance difference (p = 0.076 > 0.05) between the pre-test and the post-Control test scores. Even though, there was an increment in the post-test score (mean 204.6800**)** compare to the pre-test score (mean 195.3100), the difference was not statistically significant. The results suggest that the intervening course work on other unrelated studies does not contribute toward PI improvement.
4. We also compared the post-test scores for the experiment and control groups. In this analysis, there was a much larger and more significant difference (p = 0.000) between the post-test scores for the experiment group (mean 259.75) and the control group (mean 205.19) scores.

The results of the fault diagnosis test showed a relationship between PI and the ability to diagnose experiment faults. Figure 4 shows the relationship between the PI score for the 3 groups of participants in the fault diagnosis study with their ability to diagnose experiment faults. The experiment group with higher practical intelligence scores (Exp-Higher), gained higher score in the fault diagnosis test (slightly proportional with practical intelligence). The Control group gained lesser than Exp-Higher group, but their score was proportional to the practical intelligence. For Exp-Lower, their score was scattered with no obvious correlation. The results suggest that PI scores predict ability to diagnose experiment faults in similar laboratory equipment.

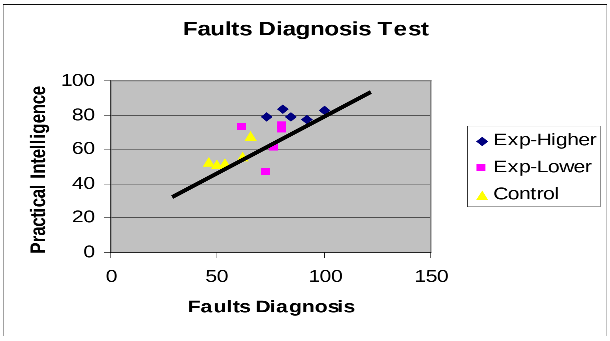

Figure 4: Results of the fault diagnosis study

6. Conclusions

The results demonstrate that we can devise effective ways to measure practical intelligence acquired by engineering students from laboratory experiences. 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 we may be able to alter student learning behaviour by including tacit knowledge tests in assessment processes. It is well known that assessment practice drives student learning behaviour [37, 38]. 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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