

Measuring Practical Intelligence: the hidden dimension of ‘hands-on’ laboratory assessment in engineering technology courses

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Abstract

Laboratory classes are valuable learning experiences and it is expected that students might acquire explicit and tacit knowledge or practical intelligence. This research has attempted to show the possibility of measuring practical intelligence that has not been assessed or measured in the past when evaluating different laboratory experiences for engineering students. These results demonstrated that practical intelligence (PI) can be measured by calculating the difference between participants’ ratings and the experts’ ratings. In the other words, the participants possessed a high level of practical intelligence, close to experts. The results demonstrate that we can devise effective ways to measure practical intelligence acquired by engineering students from laboratory experiences.

Keywords

Engineering laboratory, hands-on, practical intelligence, tacit knowledge, troubleshooting.

1. Introduction

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. 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, 3]. 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 [4], though there are differences in the way that students experience on-line and simulation labs.

In typical hands-on laboratory classes which we have observed, 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.

It is accepted that practical know-how is essential for high achievement in the workplace [e.g.5 - 7]. Furthermore, Sternberg and his colleague [10] proposed that this type of know-how or what they have called ‘*practical intelligence*’ is closely related to what Michael Polanyi [8] 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 [e.g. 2] have revealed that extensive technical knowledge is needed. 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 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.

Through their 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 unintentional learning is an important aspect of laboratory work [9]. 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 [4], 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 implicit and tacit knowledge gained through unintentional learning which might allow them to diagnose the faults of equipment. Therefore, in this study, we examine unintentional learning through experience of laboratory work and the subsequent ability to diagnose equipment faults.

2. Theoretical Basis

2.1 Laboratory ‘Hands-on’ Experience

One of the most important factors in forming engineering graduate qualities is the practical component of the engineering curriculum [1]. 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. Webb [11] wrote that the underlying reason for the value of laboratory classes is that they 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.

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, 15]. 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 [e.g. 15]. 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 [16]. For example, Dobson, Hill *et al* [16] 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 [16]. 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.

2.2 Experience or Practical Intelligence

The concept of experience through unintentional knowledge is closely related to the concept of skills, used mostly to describe practical know-how [10] and is gained through practical experience in various contexts. For instance, Sternberg and his colleagues [10] explored implicit knowledge in academia as practical intelligence, and they insisted that in order to succeed in academia, a person needs expert knowledge of that kind of environment. 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 et al. [10] describe 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 [11].

Practical intelligence seems to be acquired through experience. Kolb [12] provides four stages of experiential learning:

- active experimentation,
- concrete experience,
- reflective observation, and
- abstract conceptualization.

Ideally all these should be incorporated in the practical exercise. When a practical exercise incorporates these stages placed in a sequence, Kolb predicts effective learning-by-doing [12, 13]. Hence we 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 [6] 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 this reason, we define ‘unintentional learning’ as the process by which practical intelligence is acquired in laboratory classes, outside and beyond the stated learning objectives. For example, in one of our survey questions, students are asked why we 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.

2.3 Argument on Predicting Performance

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 [e.g. 16] 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.

2.4 Practical Intelligence Testing Instrument

In this paper, however, the author is not attempting to make forward predictions on the basis of practical intelligence measurement. The author only wishes to measure the acquisition of practical intelligence in a relatively constrained situation, a sequence of planned laboratory experiments. Psychologists prefer economical testing instruments that can be readily provided and evaluated with computer systems: the test questions and structure embodies sufficient expertise so that the result is expressed as a single numerical score.

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. For example, presented with a description of a circuit which is not operating correctly, the response items might be:

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

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 7 = 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. In an alternative approach, groups of experts, intermediates and novices provide their ratings and their scores are correlated with a measure of their expertise (3 = expert, 2 = intermediate, 1 = novice). 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.

3. Methodology

3.1 Research Hypothesis

The aim of this research is 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 author 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 proposed hypothesis to be tested:

H1: "The change in practical intelligence in engineering students measured in the context of fault diagnosis resulting from a structured sequence of laboratory classes is statistically insignificant."

If we can prove that the hypothesis is false with a high degree of probability, then we can be confident that laboratory classes influence practical intelligence in the context of diagnosing faults in the relevant equipment, 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.

3.2 Observation and informal interview

The first step in this study was to observe the behavior of students in the laboratory classes. We observed the students individually during the experiments and interviewed them informally after they had completed their assigned tasks. Through the observations and interviews, we 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. (We noted that the laboratory supervisor had perhaps overlooked providing purpose-designed wire stripping tools.)

Sample Question:

"Do you know how to strip the wire ends?"

Responses:

Student 1: "It was difficult to do that. I used a cutter, but always cut the whole wire."

Student 2: "I tried to cut and slice the insulation carefully, because the wires were too small."

Student 3: "I used pliers, gripped the insulation tight enough to pull it off."

Student 4: "I couldn't do that, the lab demonstrator helped me."

Student 5: "I used my teeth to cut the insulation and pull it off."

Students 6-9 (with minor variations): "I had to use pliers; it was easy to strip the wires."

Following the observations and informal interviews, we concluded that some of the students had previous experience of wire stripping. Students 3 and 6-9 come into this category. Other students seemed to have no prior experience (or recollection). Therefore we can conclude that students may already have relevant practical intelligence. In order to determine the extent of unintentional learning we need to assess practical intelligence before and after the laboratory class experience.

3.3 Practical intelligence involved in the experiment tasks

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 1 shows an example of the practical intelligence involved in the task of stripping the wire ends.

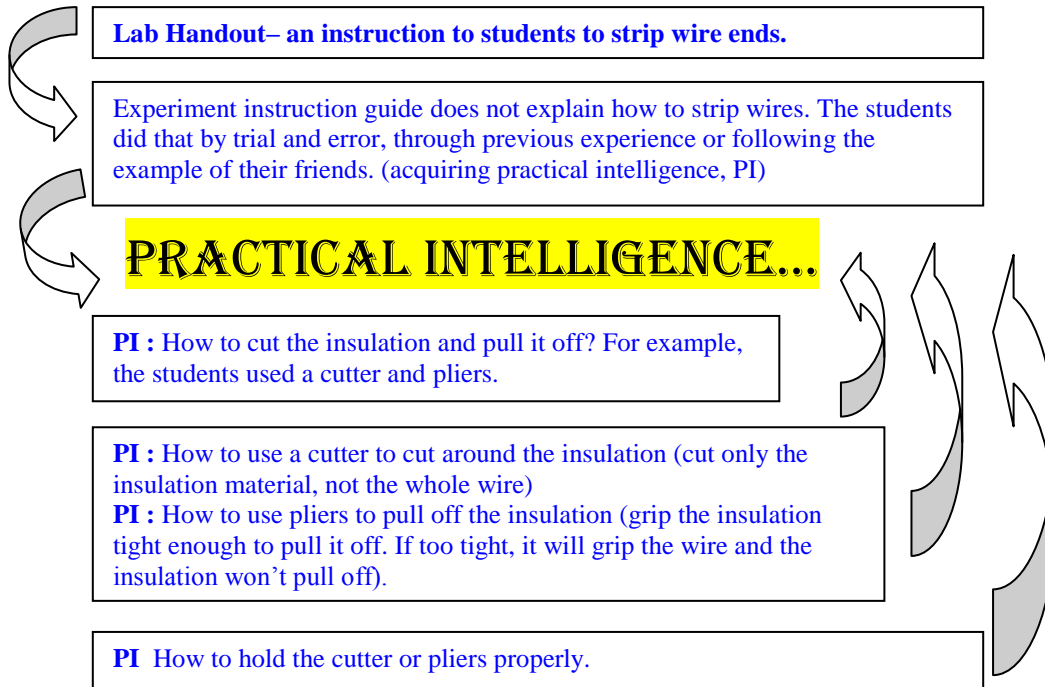


Figure 1: Practical Intelligence (PI) in the task

3.4 Practical Intelligence Testing Instruments

The Figure 2 shows a simple example of situation or problem is wire stripping. The students were asked to rate the appropriateness of different methods and tools for stripping insulation from wires.

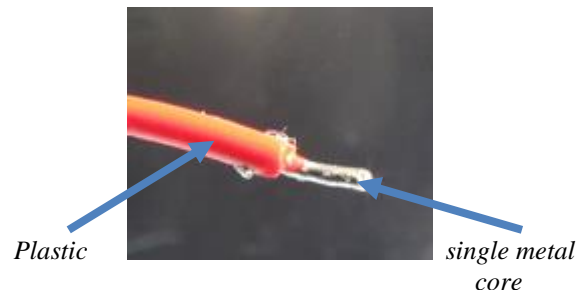


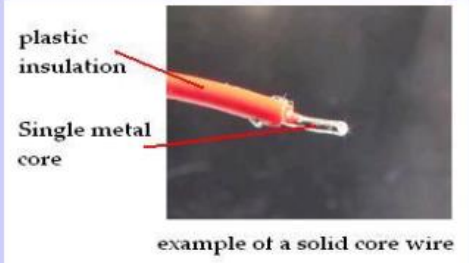
Figure 2: close-up photograph of a piece of connecting wire used in the laboratory tasks.

The response items included different types of pliers, using one's teeth, scissors and several professional wire stripping tools. Figure 3 shows example a part of online Practical Intelligence Survey (consists of situation and response items), whilst Figure 4 shows example of selected 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.

Part 2: Situation 2

You are given a wire and have to strip it. When you check the wire, you find that the wire is a solid core wire. You have been thinking about what the appropriate tools are to request from lab demonstrator to do the task.



plastic insulation

Single metal core

example of a solid core wire

Please rate the following tools or methods to strip insulation from a solid core wire.

1 (Not a good way) 2 3 4 5 6 7 (Very good way)




Figure 3 shows a survey question about wire stripping. It includes a diagram of a wire with labels for 'plastic insulation' and 'Single metal core', and a rating scale from 1 to 7. Below the scale is an image of a pair of red-handled pliers.

Figure 3: Example part of Practical Intelligence Suvey



Figure 4: Example of selection of images used for response items for wire stripping.

3.5 Methodology

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.

4. Results and Discussions

4.1 Results

The results of this investigation shows in Table 1 demonstrated that the original null hypothesis was 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:

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).

4.2 Discussions

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 closed 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.

Further research on the relationship between Practical Intelligence vs. ability of diagnosing equipment faults showed a novel relationship (Figure 5). 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 equipment. Therefore the results suggest that PI scores predict ability to diagnose equipment faults in similar laboratory equipment.

5. Conclusions

The results demonstrate that the author 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. The author was 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 author 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 behavior [13]. 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.

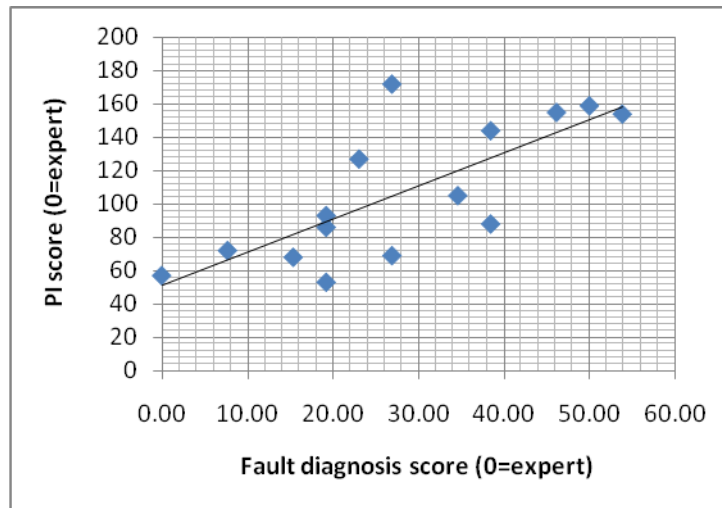


Figure 5: Results of practical intelligence (PI) proportional to fault diagnosis

References

1. Feisel, L.D. and A.J. Rosa, The Role of the Laboratory in Undergraduate Engineering Education. *Journal of Engineering Education*, 2005. **94**(1).
2. Trevelyan, J.P., Technical Coordination in Engineering Practice. *Journal of Engineering Education*, 2007. **96**(3): p. 191-204.
3. Arpaia, P., et al., A remote measurement laboratory for educational experiments. *Measurement*, 1997. **21**(4): p. 157-169.
4. Lindsay, E. and M. Good, Effects of Laboratory Access Modes Upon Learning Outcomes. *IEEE Transactions on Engineering Education*, 2005. **48**(4): p. 619-631.
5. Somech, A. and B. Ronit, Tacit knowledge in academia: Its effects on student learning. *Journal of Psychology*, 1999. **133**(6): p. 605-617.
6. Leonard, N. and G.S. Insch, Tacit Knowledge in Academia: A Proposed Model and Measurement Scale. *Journal of Psychology*, 2005. **139**(6): p. 495-512.
7. Ree, M.J. and J.A. Earles, Intelligence Is The Best Predictor Of Job Performance. *Current Directions in Psychological Science*, 1992. **June**: p. 86-89.
8. Polanyi, M., ed. *The Tacit Dimension*. 1966, Doubleday, Garden City.
9. Christiansen, F.V. and C. Rump, Getting it right: conceptual engineer. *European Journal of Engineering Education*, 2007. **32**(4): p. 467-479.
10. Sternberg, R.J., et al., Testing common sense. *American Psychologist*, 1995. **50**(11): p. 912-927.
11. Sternberg, R.J. and R.K. Wagner, Individual differences in practical knowledge and its acquisition. . 1989.
12. Kolb, D.A., *Experiential Learning: Experience as the source of learning and development*. 1984, New Jersey: Englewood Cliffs, NJ: Prentice Hall.
13. Gibbs, G., *Learning by doing*, in *FA Guide to Teaching and Learning methods*. 1988, Further Education Curriculum Review and Development Unit (FEU): London.
14. Webb, A., *Design of a Thermofluids Pump Laboratory*, in *School of Mechanical Engineering*. 2003, The University of Western Australia.: Perth.
15. Nickerson, J.V., et al. Remote versus hands-on labs: a comparative study. in *Frontiers in Education, 2004. FIE 2004. 34th Annual*. 2004.
16. Dobson, E.L., M. Hill, and J.D. Turner, An evaluation of the student response to electronics teaching using a CAL package. *Computers & Education*, 1995. **25**(1-2): p. 13-20.