Can practical intelligence from a laboratory experience be measured?

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Abstract*: Empirical studies of engineering practice suggest that implicit and tacit knowledge acquired through hands-on activities in laboratory classes is valuable in engineering practice. Implicit and tacit knowledge or "practical intelligence" occurs when a person learns unintentionally, could also be a useful learning outcome from a laboratory experience. Nonetheless, when evaluating laboratory exercises, the assessment involves only explicit outcomes and student perceptions. Practical intelligence has not yet been assessed or measured. Industry surveys provide strong evidence that engineering graduates do not seem to be aware of the kinds of practical intelligence needed in their work. This may result from the implicit devaluation of practical intelligence which might significantly impair engineering students' ability to acquire and value this knowledge. Therefore, developing ways to include effective assessment of practical intelligence could be one way to overcome this difficulty. A methodology for developing effective assessment of practical intelligence is proposed in this paper.*

Introduction

In this study, we are in the process of designing and implementing an on-line survey instrument to measure practical intelligence related to introductory electrical engineering laboratory exercises. The aim of this survey instrument is to assess practical intelligence by measuring some aspects of students' practical knowledge related to the laboratory experiments (Razali & Trevelyan, 2007). For instance, in an introductory electrical and electronics engineering laboratory, students have to do hands-on experiments. They are provided with experiment kits, tools, related equipment and an experiment handout to guide them through the required tasks. In the laboratory, the students have to follow the instructions in the experiment handout presented as explicit knowledge (School of Electrical Engineering, 2007). At the same time, through their laboratory tasks, we could expect that students might acquire or have to use tacit knowledge or practical intelligence without necessarily realizing it.

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. 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 (R. J. Sternberg, Wagner, Williams, & Horvath, 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. Tacit knowledge or practical intelligence can be defined as 'unintentional 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. Typically laboratory classes have been evaluated by assessing explicit knowledge (in reports and test answer scripts) and student perceptions (Lindsay & Good, 2005) of their laboratory experience, but for practical intelligence, we have not been able to find any research undertaken to measure it. Therefore, later in this paper we propose a measurement method for this useful learning outcome. Relevant literature was reviewed to inform this study.

Hands-on experience in engineering laboratory

When we speak about an engineering education, particularly in the context of experience, hands-on skill, thinking skills, intellectual skills, problem-solving skills, and the like, we often refer to them in the context of application in engineering laboratory classes(Trevelyan, 2007). One of the most important factors in forming engineering graduate qualities is the practical component of the engineering curriculum (Feisel & Rosa, 2005). 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. With this valuable experience, engineering students might be more effective to the extent that they are able to solve the diverse and often highly challenging problems they confront in the laboratory classes.

Through their action of “doing” the exercises in laboratory, experience will develop either intentionally or unintentionally, and we expect that students will acquire practical intelligence concurrently. It is possible they may gain experience sufficient for troubleshooting: to be able to detect and solve problems or diagnose experiment faults. Therefore we hypothesize that unintentional learning is an important aspect of laboratory work (Razali & Trevelyan, 2007). But the question is, do the students who gain experience during their laboratory classes possess a high enough level of practical intelligence through unintentional learning which might allow them to diagnose experiment faults (Razali & Trevelyan, 2007)? Thus, in the further study, we will examine the effect of unintentional learning through experience of laboratory work and the subsequent ability to diagnose experiment faults.

In this article, we are interested, in particular, in students’ practical intelligence as measured by one important aspect of such intelligence, implicit knowledge—one’s knowledge of how to get things done in the laboratory classes, which usually is not explicitly taught and that often is not even verbalized. We view implicit knowledge 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.

Implicit knowledge as a theoretical framework for assessing student’s experience

Sternberg and his colleagues (see (R. J. Sternberg, 1993; R. J. 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 (Schon, 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” (2000). Further, Sternberg and his colleagues (R. J. 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 (see e.g., (R. J. Sternberg et al., 2000; R. J. Sternberg & Wagner, 1993; R. J. 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.

.Sternberg and his colleagues constructed their instrument by interviewed experienced and highly successful individuals in the field (5 academic psychologists, all of whom were full professors) for the purpose of identifying representative work-related situations in which implicit knowledge was important. In the interview, they asked them to describe typical work-related situations and their responses to the situation. On the basis of these interviews, their theoretical framework and a review of past literature, a set of 12 work-related situations was constructed that required subjects to make judgment and decisions. The pilot set of work-related situations was sent to faculty of psychology and subsequently was revised on the basis of their comments.

Testing practical intelligence

The measurement of practical intelligence

Because people often find it difficult to articulate their practical intelligence, we measure it in the responses individuals provide to practical situations or problems, particularly those situations in which implicit knowledge is expected to provide an advantage. The measurement instruments used to assess practical intelligence typically consist of a series of situation descriptions, each of which has a number of associated response items. Our proposed instrument consists of situation descriptions, each of which presents a problem relevant to the domain of interest (e.g., a particular problem in a laboratory task). The response items were created as a result of careful observation of both students and experts and include highly appropriate responses and also common inappropriate responses made by students. Respondents are asked to rate, on a Likert scale, the quality or appropriateness of each potential response to the situation. Situations in which implicit knowledge is relevant are often those for which the appropriate responses cannot be drawn from knowledge of explicit procedural rules. In fact, the more appropriate responses may even contradict formal, explicit knowledge.

We are currently in the process of designing and implementing 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 between July and September 2008.

Research aim, method and hypothesis

Because the study goal is to investigate if a practical intelligence acquired during the laboratory exercise, it is desirable to control extraneous variables that affect learning. So, a laboratory experimentation method with a repeated measures design was chosen as a suitable approach that provided a way to control the effect of extraneous variables (Breakwell, Hammond, & Fife-Shaw, 1993). The survey instrument will be used to evaluate initial experience for a group of engineering students before attending the laboratory exercise (pre-lab), and a similar test will be used to determine their experience after the laboratory exercise (post-lab). Another control group will be asked to complete the survey twice with a similar elapsed time between exposures as a first group, but without completing the laboratory task.

Then we will test a null hypothesis that is there is no statistically significant difference in the results between the respondents who perform the laboratory exercises and the control group. If this hypothesis is proved to be false, we can conclude that we can detect the acquisition of implicit knowledge. The results may also show if there is any difference in the level of practical intelligence among students before and after attending the laboratory experiments.

Development of Instrument

Individual observation and practical intelligence involved

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 second half of 2007. We observed the students individually during the experiments and noticed how practical intelligence is involved in the experiment tasks. In one of the exercises, students had to strip both ends of a wire. They had to follow the sequences or direct instruction in the experiment handout presented as explicit knowledge (School of Electrical Engineering, 2007). At the same time, without necessarily realizing, they had to use their practical intelligence because the experiment handout does not explain how to strip wires. We noticed that some of the students used their creativity to strip ends of wires;

they used a cutter, nail cutter, alligator clip or their teeth to cut and pull off the insulation. Some of the students were able to use pliers or stripping tools. Many students asked lab demonstrators to show them how to do that. For example, if they used a cutter and pliers to strip the wire. Nobody taught the students how to use a cutter to cut around the insulation (cut only the insulation material, not the whole wire) and how to use pliers to pull off the insulation (grip the insulation tight enough to pull it off; if too tight, it will grip the wire and the insulation won't pull off), even how to hold the tools properly. The students were able to do that by "doing" the thing, either by trial and error, through previous experience or following the example of their friends.

Later we interviewed them informally after they had completed their assigned tasks. Following the observations and informal interviews, we concluded that some of the students had previous experience of wire stripping. Other students seemed to have no prior experience (or recollection). Therefore we can conclude that students may already have relevant practical intelligence and would gain unintentional experience and knowledge when they were doing the experiments. In order to determine the extent of unintentional learning we need to assess practical intelligence before and after the laboratory class experience.

The samples of situation and responses for the survey instrument as shown in Figure 1.

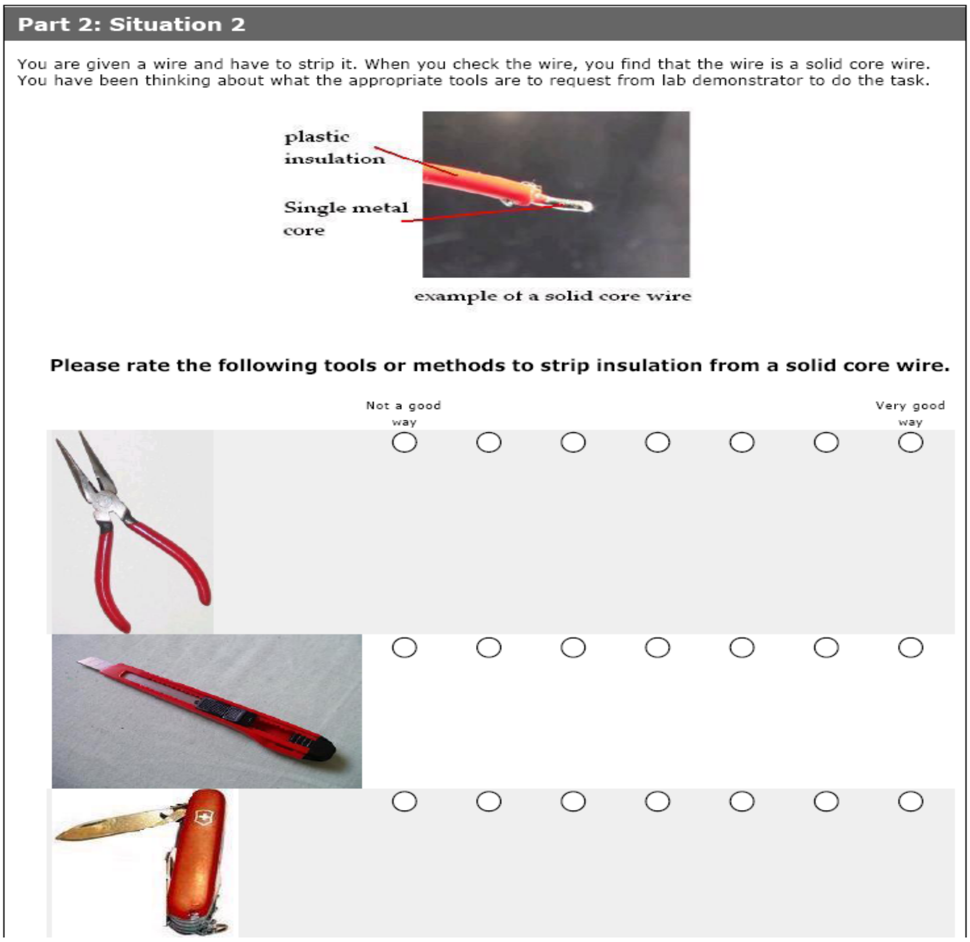

Figure 1: Samples of situation and responses (in pictures)

In this research, we require two surveys; *a pre-lab survey instrument* before attending the laboratory and *a post-lab survey instrument* after attending the laboratory. The same instruments will be given to a control group.

We 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. The respondent score is calculated by calculating the deviation from the average responses of reference scores. The reference scores are 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. We need to modify this by the variance of the expert responses: the deviation should be calculated from the respondent score deviation from the experts' mean, divided by the experts' variance. Thus, if the experts differ on the appropriateness of a particular response item, it does not matter how the students respond. If the expert responses agree closely, then the student deviation will contribute a significant score increment. High scores correspond to a large overall deviation from the expert responses.

Results from preliminary empirical studies

Pilot tests of on-line survey instrument

A pilot version of the online survey instrument was tested with 25 second year mechatronic engineering students and 18 postgraduate students in April and May 2007. This instrument was simpler in structure where the response items were chosen such that only one provided the most practical response. Participants merely selected what they thought was the most appropriate response item. The analysis of *t-test: two sample assuming equal variance* shows the results demonstrated that there is a significant difference in the level of practical intelligence between the postgraduate students and the second year students (*t-stat*=2.4344, *p(T>=t)one tail*=0.0097 <0.01 significance level). However several of the participants (15%) omitted responses (suggesting that they did not understand questions) and we realised that there were multiple interpretations of some of the response items. This study confirmed findings in the literature that response items require rating scales so that participants can rate the appropriateness of each item. Feedback from participants in the pilot test was used to improve the practical intelligence test.

This pilot study also confirmed the need for further 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 we are both experienced teachers, it was sometimes difficult to understand the most simple and basic gaps in their knowledge.

Further research

On the assumption that we 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, and between the control groups, we will proceed to the confirmation stage of this study. In the third phase of this research we will select a sub-sample of survey respondents and invite them to participate in a simple fault diagnosis task on some of the equipment they will have used in their laboratory classes. These students will be observed performing a troubleshooting task and their performance will be evaluated. We expect that this study will provide qualitative data that can be used to help understand the contribution of learning implicit and tacit knowledge to the ability to perform fault diagnosis tasks. We also hypothesize that practical intelligence acquired in laboratory experiments will be correlated with performance in troubleshooting tasks on similar circuits.

Conclusions

In this paper we have attempted to show the possibility of measuring the acquisition of 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 may provide a way to measure that elusive component of engineering laboratory experiences referred to by most people as "hands-on practical experience". In the other words, if we can devise effective ways to measure tacit knowledge acquisition by engineering students we may be able to alter their learning behavior by including tacit knowledge tests in assessment processes. It is well known that assessment practice drives student learning behavior (Gibbs, 1988). 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.

Testing tacit knowledge 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 tacit knowledge and possibly relate better to trades people and technicians on whom engineers need to rely to achieve practical results from their work.

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