A reflective closed loop approach for implementing a new authentic assessment-based teaching facility for electric motor and drive systems

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Structured abstract

BACKGROUND
A new teaching facility with a focus on electric motor and drive systems has been implemented at the University of Wollongong. This facility aspires to use authentic assessment principles to assist in preparing students to properly utilise electric motor and drive systems in professional practice. In an attempt to realise this aim, the implementation of this facility was undertaken using a reflective closed-loop approach, addressing the educational outcomes achieved by the students. Setting a holistic scope for the implementation beyond technical concerns to include educational outcomes was critical to the success achieved and has laid the foundation for further improvements.

PURPOSE
The motivation for this work was to implement a teaching facility that successfully assists in preparing students for professional practice with electric motor and drive systems.

DESIGN/METHOD
The facility and associated curriculum was designed, built and implemented based upon the principles of authentic assessment and industrial expectations of engineers working with electric motors and drives. A number of methods were employed to reflectively assess student attainment and the effectiveness of the facility, including before and after testing of students undergoing training on the facility; the results of which were used to improve the facility and associated curriculum. This cycle of training, reflective assessment and improvement of the facility has been undertaken upon two successive elective classes of final-year undergraduate and post graduate engineering students.

RESULTS
The facility and associated authentic assessment worked well and students' attainment measurably improved, although some of the highly aspirational aims set for student attainment were not met after training on the facility. The reflective assessment of student performance before and after training allowed for the identification of avenues of improvement in the use of the teaching facility to reach the aims set. Some of these avenues have been successfully employed, improving attainment while others have been identified for future work.

CONCLUSIONS
Training on the facility has resulted in measurably improved student attainment in using electric motor and drives systems in engineering practice. Setting the scope of implementation of the training facility beyond purely technical concerns to include educational outcomes has been crucial to the success achieved thus far and the identification of opportunities for future improvements.

KEYWORDS
Authentic assessment, electric drives

Introduction

A new teaching facility with a focus on electric motor and drive systems has been implemented at the University of Wollongong as part of a new Power Electronics and Drives teaching laboratory. This facility aspires to use authentic assessment principles to assist in preparing students to properly utilise electric motor and drive systems in professional practice. In an attempt to realise this aim, the implementation of this teaching facility was undertaken using a reflective closed-loop approach, addressing the educational outcomes achieved by the students.

Implementation of the facility was carried out as a technical project that encompassed all stages of design, construction, assembly and testing, with five fully operational units being built. As part of the testing phase, the facility has been used to teach in two successive elective courses on power electronics and drives in 2012 and 2013; the results of student performance have been used to refine the facility's systems and their use.

Background

The goal of the project was to provide facilities that would assist in preparing students to properly utilise electric motor and drive systems in professional practice. Initially this preparation was considered to be simply adding a practical component to the current training of students. However, during the early stages of the project design, a more aspirational goal evolved; to raise the standard of engineers graduating into practice.

Surveys of industry attempting to determine the skill required of graduate engineers were carried out, during which accounts of costly technical mistakes repeatedly being made by engineers attempting to utilise electric motors and drives were uncovered. The recurring theme within these accounts was that the mistakes could have been avoided with some threshold level of competency. These accounts or “war stories” inspired an aspirational project goal of improving the standard of engineers graduating into practice and have become a guiding force in the development of the equipment and the laboratory design. They have provided: motivation to attempt to improve students' training, valuable insight into what the threshold competency is that a student needs in order to successfully practice and a means to assess student attainment toward this objective.

The implementation of the facilities was undertaken as an engineering project with an objective to deliver positive educational outcomes for students using a combination of a teaching facility and an associated curriculum. The deliverables of this project were deliberately set beyond purely technical concerns to include the educational outcomes to maximise the chance of achieving them; rather than limiting the scope to solely hardware and software. This decision determined that the project approach was necessarily educationally reflective according to Biggs’ (2003) definition of reflection.

Throughout the project, the education of students was dealt with as a process; a process that was usefully addressed in engineering terms by an analogy to a closed loop feedback controller as shown in Figure 1 (Ogata, 1998). The key elements of this closed loop system are: the training facility, students, assessment and a desired level of competency. In control engineering terminology these are the actuator, plant output, feedback sensor and set point respectively.

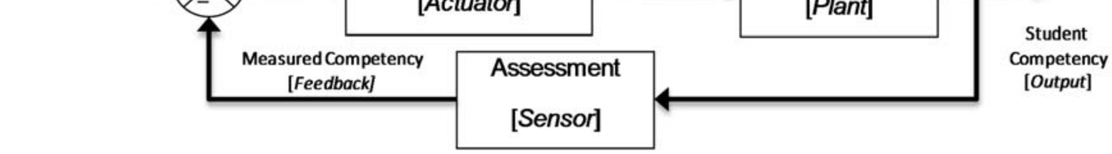

Figure 1: Closed loop feedback controller analogy of student education

Viewing student education via this analogy provided a number of benefits: it assisted in a clear definition of the components involved; described their interaction and uncovered issues that had to be dealt with for successful operation of the system. These issues were:

- Which particular students were to be taught (plant)?
- What specifically is the actual level of competency sought (output)?
- How is student competency measured (sensor) and what are the limitations of measurement?
- What is the target competency (set point) and how is it defined so that:
    - It could be compared with the measured competency (feedback)
    - A difference between the desired and measured competency could be found and can usefully influence the use of the training facility to address it (error drives the actuator to reduce this error).
    - The chances of achieving the desired competency (output) were maximised.
- What should the training facility (actuator) consist of in order to maximise the chances of producing the desired output.

Among these, three issues in particular are of key importance: a useful definition of the level of student competency sought (output), the means used to measure this competency (sensor) and a useful definition of the target level of competency (set point).

The motivation provided by industrial “war stories” proved fruitful in addressing these key issues. Firstly, the desired output of the project was students who will not make the mistakes of those involved in the “war stories”. That is, they would be competent enough to successfully avoid the mistakes of others.

The degree of competency required to avoid these mistakes is multi-layered. It requires that students not only understand what electric motor and drive systems are and how to use them, it also requires that students know the reasons why they are used in this way. In the field of information studies, this level of understanding is succinctly defined as wisdom by Zeleny (2006), importantly capturing its hierarchical nature; understanding what things are, how to use them and why. Utilising this definition of wisdom the desired output of the teaching facility could therefore be usefully defined as engineers that practice with wisdom in the field of electric motors and drives.

The “war stories” also proved useful in addressing the key issues of establishing a target level of competency and measuring student attainment towards it. These stories were used as the basis for a series of hypothetical scenarios based upon the accounts of costly mistakes made in industry. These were put to students in addition to their traditional graded laboratory assessment in an attempt to measure if they had mastered all of the required learning objectives and combined them into a competency that would enable them to avoid the mistakes of others. Thus demonstrating they had achieved the target level of competency – engineering wisdom.

The issues for the project identified using the closed loop controller analogy for student education were addressed as follows:

- The intended student audience (plant) for the project included a variety of disciplines and educational levels. Electrical, mechanical and mechatronic engineering students were to be taught at undergraduate, post graduate and continuing education levels.
- The level of student competency sought (output) was graduates who are able to properly utilise electric motor and drive systems in professional practice. This requires that they practice engineering with wisdom including the hierarchical understanding of what electric motor and drive systems are; how to use them and why they should be used in a particular way in specific circumstances.
- The assessment (sensor) used was a composite. It was primarily based on student laboratory exercise books which were augmented by questionnaires derived from engineering “war stories” and direct observation of the students.

- The target competency of the system (setpoint) was students who could successfully complete the traditional laboratory assessment tasks and negotiate all of the “war story” situations when presented to them as hypothetical scenarios. This was chosen to try and produce the desired outcome of students that understood the what, how and why of electric motors and drives and should ultimately successfully negotiate “war story” situations in industrial practice.
- The training facility (actuator) included equipment and curriculum designed to maximise the chances of producing engineers that practice with wisdom.

Approach

Implementation of the facility to achieve the desired aims was undertaken as an engineering project. The project was to develop and implement a training facility, associated curriculum (actuator) and assessment (sensor) in a closed-loop educational process to produce (output) students who are able to properly utilise electric motor and drive systems in professional practice – engineers who can practice with wisdom as defined by Zeleny (2006). The training facility, curriculum and assessment formed separate but related deliverables of the project; importantly they all had to perform adequately to achieve the desired result.

In order to maximise the chances of producing engineers with the requisite wisdom, it was decided that the facility would be developed using authentic assessment principles (Janesick, 2006). Specifically training and assessment tasks would be realistic, require judgement, replicate problems faced in the workplace and require students to actually use electric motor and drive systems. To this end real industrial components would be used and assembled in a configuration that was as realistic as possible. Also the amount of simulation within the facility would be minimised as far as practicable, working within the constraints of the project context. Students training on this equipment would have an excellent opportunity to develop practical skills in working with real industrial equipment.

The implementation of the training facility included a detailed specification of the system requirements; component and system level design, assembly and testing of the resulting system. This process of developing the equipment was highly iterative and closed loop in nature. Frequent equipment testing was conducted throughout to ensure that the various specifications and requirements were being met. Often, issues encountered in later stages of implementation required revisiting earlier stages for resolution. The testing of the facility included testing of the educational outcomes. This implementation methodology was similar to that used in the development of military and aircraft simulators called Verification, Validation and Accreditation (Engel, 2010).

The training facility that was developed is shown in Figure 2 and Figure 1. It consisted of:

- Two squirrel cage induction motors coupled together by a torque transducer. One motor acting as a prime mover and the other as a load.
- The prime mover can be operated by one of three common industrial drives: a direct on line (DOL) starter, a Thyristor Soft Starter or a Pulse Width Modulated Inverter.
- The load motor is supplied by a Four Quadrant Regenerative Inverter with controllable torque. The torque absorbed by the load motor is programmed to simulate real loads (pumps, fans, etc.) as appropriate to the lesson being taught.
- The system is operated and controlled by an industrial Programmable Logic Controller (PLC) which handles equipment mode switching and control.
- A personal computer loaded with Human Machine Interface (HMI) software allows the human user to interact with the equipment via a graphical interface. Within the HMI a number of graphical screens were developed to suit the individual exercises.
- Sensors measuring shaft speed, motor temperature, currents and voltages were installed throughout the system and connected to a data acquisition system. The sensor data was viewed and logged using National Instruments LabVIEW software.

Figure 2 Teaching facility control station **Figure 1 Teaching Facility motor assembly**

The development of the curriculum and the training facility were inter-related; the facility had to be capable of delivering the required exercises for the curriculum. The curriculum requirements tended to drive equipment design in two ways: if a curriculum aim was to familiarise students with a certain piece of equipment the facility had to include it: if the aim was to examine a particular phenomena, it had to be present and visible in the facility, often requiring sensors and data acquisition.

Development of the curriculum was guided by constructivist principles laid down by Tyler (1949) ,Biggs (1993, 2003) and Kafai & Resnick(1996) . The curriculum was planned as a staged progression of students towards the desired wisdom. Importantly, Tyler (1949) viewed instituting a curriculum of teaching as a closed loop process. The educational objectives of each laboratory session were formulated; the exercises to reach these objectives were selected, the organisation of the exercises decided and the measure of successfully reaching each objective was determined. Importantly the key objectives of each laboratory was stated in the lab notes, they began at the component level by examining electric motors, drives and loads in isolation at a detailed level and progressed onto examining the systemic behaviour of a motor-load-drive system when the individual components were combined.

The assessment associated with the curriculum had to fulfil many requirements. The assessment had to:

- Be capable of determining if a student had achieved the educational objectives of each exercise and was progressing towards the desired level of mastery – in this case the engineering wisdom.
- Be a true indication of individual student competency.
- To enable an incomplete or faulty mastery of the subject to be analysed, the reason diagnosed and appropriate remedial action identified, including where the remedial action was required (equipment or curriculum).
- Be authentic and assess students using industrially significant measures.
- Ideally motivate students to learn by virtue of being of clear relevance to professional practice.

These assessment requirements were addressed with a three tiered approach. Firstly, via the use of traditional graded assessment of laboratory exercise books. These were designed in accordance with the educational objectives of each laboratory session and consisted of background material and set out a number of experimental measurement and analysis tasks for the student to undertake. The exercises and analysis tasks were structured towards building the desired wisdom. The progress of students through the individual tasks was indicative of their level of understanding and offered greater opportunity to identify at what point in the hierarchical progress towards wisdom they may falter.

The second major method of assessment was based on a number of industrial “war stories”. Effectively, four key problems were used, each of which was turned into two different scenarios that could be posed to students in questionnaires before and after their training in order to assess their attainment level and the impact of training using the facility. These scenarios met most of the assessment requirements with the critical exception of enabling analysis of an incomplete mastery and identifying remedial action. While they could identify if a student had reached the desired level of wisdom (or not); they were not particularly useful in determining why it was not reached or what to do about it.

The final method of assessment was direct observation, discussion with students and the coaching of the students during the laboratory classes. The first two assessment methods tended to focus on the interaction of the student and the subject matter being taught. They did not offer an insight into other factors that can impact on student attainment, such as faulty equipment, time constraints within the laboratory, student mastery of the local language, etc. Direct observation complemented an analysis of student workbooks and offered additional information in diagnosing problems with the hardware, software or curriculum.

Coaching of students was carried out with some caution to ensure that students were not simply given the answers to the assessment tasks without actually understanding them. Coaching offered significant insights into a variety of learning related issues and was responsible for identifying a number of educational improvements in the curriculum.

During the course of the laboratory work and after submission of assessment relating to the laboratories student feedback provided informally and via faculty survey about the teaching facilities and the associated curriculum was positive.

Assessment, evaluation and data analysis

The facilities were used with an elective course on power electronics and drives delivered to final year undergraduates and post graduates in 2012 and 2013; the results were used to refine the systems and their use. The assessment of student performance identified a number of issues, the most significant of which were pedagogical. While some minor software and hardware issues were identified these were minor by comparison. This highlighted the value of including the educational outcomes in the scope of the engineering project.

Analysis of student performance in a variety of assessment areas yielded significant pedagogical improvements. Due to length constraints, this paper will focus mainly on the analysis of student performance in the scenario questionnaires given before and after training on the facilities and the resulting pedagogical improvements that were implemented:

The questionnaires were given to students before and after training in an attempt to measure the effect that use of the teaching facilities had on student knowledge and ability. The questionnaires given to students posed four key problems testing important areas of student knowledge. The same problems were posed to students before and after training disguised in two different industrial scenarios. Students were tested on their understanding of:

1. Current drawn by an induction motor – the most common electric motor in industry.
2. The operational behaviour of an induction motor, specifically how motor torque and power output varies with speed.
3. The capabilities of Pulse Width Modulated inverters in varying induction motor speed.
4. The selection of appropriate motor drive types for use with different types of real world loads.

An example of a scenario presented to students to test their ability is:

> *You are a supervising engineer on an industrial site. A fault is reported to you – a fluid pumping system is not delivering flow as it should. You despatch an electrician and a mechanical technician to investigate. They report back that all valves in the system are open and the pump motor is turning and drawing about 25% of its full load current. They conclude that the pump and motor are working OK and that there must be a blockage elsewhere in the system. They suggest that arrangements be made to shut down the system, disconnect the pipe work and look for blockages. Do you agree?*

To successfully negotiate this scenario, a student needs to understand some fundamentals of induction motor operation and be able to contextualise them. In this case, that an induction motor will draw a significant amount of current to simply generate a magnetic field and begin to rotate before providing any useful mechanical output – pumping a fluid, for example. This is equivalently referred to as the magnetising current or more instructively as the “no load” current of the motor. This current is typically is 25-33% of the full rated current of the motor. In the scenario presented, students needed to recognise that the current drawn was around the motor “no load” current. Therefore the motor was doing no mechanical work and there was likely something wrong with its mechanical connection to the load.

The archetypical example of this in industry occurs when a motor becomes disconnected from its load. This scenario is based on industrial accounts of pumps being disconnected from their motors due to coupling failures. The cause of the lack of flow is often misdiagnosed and the pumping system is then shut down and pipe work dismantled and searched for a nonexistent problem, wasting time and money. An engineer practicing with the desired wisdom would immediately look at the motor coupling for the real source of the problem in this case.

The other key problems posed in the scenarios required similar levels of engineering knowledge and feats of understanding and deduction. The questionnaires were used on both the 2012 and 2013 cohort and the results are shown in Table 1. The questionaries were not compulsory for students and were not part of their assessment – this was established after careful consideration. The aim was to get a candid and accurate picture of an individual student’s current ability. It was thought that if the questionaries were compulsory, students researching or working collaboratively may distort the data. An unfortunate result of this decision was that not all students completed and submitted the questionnaires.

	Percentage of correct responses					
	Before lab training		**After Lab training**		**Effect of training**	
Scenario	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**
1. Current drawn by an induction motor	0%	0%	11%	34%	11%	34%
2. Operational behaviour of an induction motor	0%	7%	17%	5%	17%	-2%
3. Capabilities of Pulse Width Modulated inverters	100%	41%	78%	50%	-22%	9%
4. Selection of appropriate motor drive types.	10%	7%	11%	41%	1%	34%
Total Responses received	10	29	9	22		
Class Enrolment	31	37				

Table 1: Results of scenario questionnaire assessment

Student performance was measurably improved after training on the teaching facility; however in general the results were lower than hoped. In part, this is believed to be indicative that the goal set for the teaching facilities was highly aspirational and indicative of the additional work required to reach the goal. Referring to Table 1 for the results in 2012, it shows that student performance was poor on scenarios 1, 2 and 4 before training with a slight improvement after training. Performance on scenario 3 was good both before and after training, possibly reflective of a high level of student knowledge prior to training.

Analysis of the 2012 student responses to the questionnaires and their laboratory workbooks identified two issues that appeared to underpin students' poor performance in scenarios 1, 2 and 4: The first was that students appeared to have difficulty seeing the practical application of their experimental work. The second was that students appeared to be only considering each lab exercise in isolation and not building them into the overall hierarchical knowledge of the desired wisdom.

In an attempt to deal with the first issue and to help students see the practical application of each laboratory exercise, illustrative “war story” scenarios were added to the text of the student laboratory notes adjacent to the exercises in order to provide students with knowledge relevant to the scenario. To deal with the second issue, key questions leading towards the desired overall knowledge were placed throughout the experimental procedures to prompt students to connect individual exercises into the desired outcome.

Scenario 4 required students to understand the comparative performance of different motor drive types when used with particular loads. Student performance in scenario 4 was potentially influenced by two additional factors. Firstly, upon reviewing the laboratory notes, it was clear that re-ordering the exercises to juxtapose key motor and drive combinations would assist in student understanding. For example when selecting a drive for a heavily loaded crane winch a mistake often made is to select a Thyristor Soft Starter that will perform poorly, in this case a PWM Inverter is more appropriate. With the ordering of exercises in the 2012 notes, these load and drive combinations were not tested one after the other so a stark contrast in their performance was not made. Secondly the laboratory dealt with loads as abstract classes of loads without reference to specific, illustrative, practical examples.

To deal with the issues in scenario 4 the laboratory exercises were re-ordered to make a number of important comparisons in performance clear and the graphics of the HMI and the laboratory notes were altered to show pictures of example load types to assist students in understanding the practical ramifications of the experimental exercises.

The laboratories were run in 2013 with the revisions in the HMI and the laboratory notes in place. During the 2013 laboratory sessions it was observed that students were still struggling initially to connect the practical exercises into an overall understanding when carrying out the experimental work that would help them deal with scenario 1. The exercise required students to measure induction motor current under increasing mechanical load; plot their results and formulate a relation that would provide a way to estimate motor power output based on current drawn. It appeared that in the process of logging data and analysing it they were focussing on the mathematics and losing the physical understanding of what they were doing. While most students could plot the data and correctly find a linear relation of the form $y = mx + b$; many, when initially questioned, could not explain the physical significance of the plot.

During the 2013 lab classes some coaching was employed to resolve this problem. Students were specifically asked ‘what is the physical significance of the offset in your relation?’, ‘what is the physical significance of the gradient?’ and ‘how do these things relate to your understanding of how an induction motor operates?’ As students answered these questions, the physical interpretation of their data and analysis began to crystallise. They were able to articulate that when an induction motor is energised, the initial current flowing into the motor establishes a magnetic field and magnetically couples the stationary part of the motor to the shaft and begins to spin it; this is represented by the offset in the linear relation. Once the motor is spinning, current drawn beyond the magnetising current is proportional to mechanical shaft power delivered by the motor to a load; this is represented by the gradient of the relation.

Analysing the 2013 student responses to the questionnaires showed that student performance was poor on Scenarios 1, 2 and 4 before training while performance on Scenario 3 was moderate, interestingly much lower than the 2012 result. After training, student performance had significantly improved on Scenarios 1 and 4. Minor improvement was evident in Scenario 3. No improvement was seen in Scenario 2.

The performance improvements in scenario 1 and 4 are attributed to the actions taken including: the addition of key questions and illustrative “war stories” to the student texts;

coaching around the material relevant to scenario 1; re-ordering of exercises relevant to Scenario 4 and improvements in the HMI and lab notes relevant to Scenario 4.

The drop off in student performance in Scenario 3 was surprising. The high student performance in 2012 led to minimal improvements being made on the material relevant to this scenario. It appears that the high level of student knowledge prior to the training has concealed some deficiencies in the training that has only been uncovered by the 2013 cohort. Further work is still required to determine the cause of this poor performance.

The continued poor performance on Scenario 2 was attributed to ongoing difficulties for students being able to see the practical application of their experimental work and building the requisite hierarchical knowledge or wisdom sought. The laboratory classes posed a series of sequential measurement and analysis exercises that were intended to build the wisdom required to successfully deal with this scenario. Examination of student lab books for both 2012 and 2013 indicates that students were encountering difficulties with the final exercises in the sequence and were not in a position to build the wisdom required.

Further work on the curriculum is required to progress towards the project goals. This work should include the following: consolidation of the changes that have led to improved performance in Scenarios 1 and 4 including those made by coaching in the laboratory classes; development of teaching to build the requisite wisdom to deal with Scenario 2 and diagnosis of the cause in reduced performance in Scenario 3 within the 2013 cohort.

Conclusion

Training on the drives teaching facility measurably improved student performance; however students did not fully reach the highly aspirational goals set for the teaching facility. A number of issues that prevented students from attaining the desired level of competency were identified; the majority of which were pedagogical. Accordingly, a number of significant pedagogical improvements were implemented in course materials and procedures that measurably improved student performance from 2012 to 2013. A number of issues and areas requiring further work to reach the desired aspirational goals of the teaching facility have also been identified.

The inclusion of educational outcomes has been crucial to the successes achieved in implementing the facilities. If the scope of the project had been limited to purely technical performance, the major issues preventing students reaching the desired levels of attainment would not have been identified or dealt with. The improvement in student performance that was achieved demonstrates the value of setting a holistic scope for the project implementation beyond technical concerns to include educational outcomes.

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