Full Paper

Introduction

Many Universities are adopting a Blended Learning approach where students can access their learning at a time that suits them. This is challenging in an Engineering context where Laboratory time forms an integral part of the learning experience. This laboratory experience could be provided through the use of simulated environments or remote access.

Often forgotten in a world of 24/7 learning is that students' can lose the ability to acquire formative feedback from instructors in a face-to-face environment. Students are left to construct their own feedback which can often be incomplete or even incorrect.

Maintaining the integrity of the learning experience through practical work is important. If learning is to be taken outside the classroom, a means must be found to replicate the personal and instantaneous feedback that is typically provided by trained Lab Supervisors.

A significant number of our Units contain practical exams where students' hands-on skills are assessed. Students are required to build and configure computer networks under exam conditions. A number of years ago we changed the assessment method to a fully automated system. Student work is automatically collected at the end of the exam and the configurations are assessed to determine student grades. This software also provides personalised feedback which is then returned to students for self-reflection.

We propose to move elements of this assessment system from the exam scenario to the lab environment, allowing students to undertake lab tasks in situations where instructors may not be available, and to submit their lab work for immediate assessment and feedback. We expect that the outcomes of such a trial would improve student learning.

Motivation

Many Universities are evaluating, or moving to, a blended learning environment. Some advantages of this paradigm include 1) students can work at their own pace; 2) this mode can better cater for individual personal differences (eg employment status), and 3) that it can improve access for students (geographical status). Providing blended learning is challenging in an Engineering context where practical skills are considered important. In our study area, computer networking, having students acquire the practical skills to build computer networks using real equipment is essential. A simulated environment often does not reproduce the common problems that are faced when establishing real networks.

We were inspired by the success of our practical exam automarking system to build a Virtual Lab Supervisor that could asynchronously collect and examine student device configurations, and to dynamically generate formative feedback. We believe that access to such a tool can enhance the student experience, and increase opportunities for consolidating their learning.

Previous Work

Blended Learning can be defined as:

> "*At its simplest, blended learning is the thoughtful integration of classroom face-to-face learning experiences with online learning experiences. There is considerable intuitive appeal to the concept of integrating the strengths of synchronous (face-to-face) and asynchronous (text-*

based Internet) learning activities. At the same time, there is considerable complexity in its implementation with the challenge of virtually limitless design possibilities and applicability to so many contexts." (Garrison & Kanuka, 2004)

With this in mind, Blended Learning can and should augment the opportunities for learning by offering experiences outside of the traditional classroom. These experiences would not only enhance the learning opportunities for students who cannot attend the face-to-face, but would allow students to practice techniques and skills in their own time.

In the Engineering disciplines, one approach to a Blended Learning strategy is to provide increased access for students to practical exercises using real equipment via the use of remote laboratories. Traditionally these experiences have been face-to-face mainly because of equipment access practicalities. There are many examples of remote laboratory facilities presented in the literature. In the Electrical Engineering disciplines, these can range from simulations to remotely controlling or configuring real hardware. An overview of various remote laboratories can be found in (Gomes & Bogosyan, 20009).

Challenges in providing a Blended Learning Laboratory environment include:

- Feedback is delayed where student work is evaluated by tutors/peers after a student submits. New tools are emerging that provide immediate feedback in a restricted, simulated environment. However, as far as we know, there are no current systems to allow automated provision of timely feedback on open-ended student work
- Providing remote access to physical network devices in a way that students can construct networks from alternate locations on/off-campus is difficult
- Providing tutors for students wishing to study in their own time is challenging, particularly considering weekend and after-hours study

Swinburne University has invested heavily in a state of the art Networking Laboratory (Klimovski, Cricenti, & But, 2011). Given this investment, it seems logical to expand access to these facilities to provide a Blended Learning experience. However, the challenge remains in providing timely feedback given the online 24/7 context.

When students are engaged in a task it is important that feedback is provided as quickly as possible so that students have the opportunity to change their habits (Nicol & MacFarlane-Dick, 2006). In the context of online lab work, this involves giving the student feedback regarding mistakes made as soon as is practical, so that they can rework or repeat the exercise. In an asynchronous environment where an instructor is not always available, lack of timely feedback can impact on student learning outcomes.

One possible solution to this problem is to provide a model solution, but this does not encourage the student to learn through making mistakes. Alternatively, one can develop tools to automatically assess student work and generate feedback. Automatic assessment is not a new concept, and has been used in marking programming exercises, see (Ihantola, Ahoniemi, Karavirta, & Seppälä) for examples of some of the tools available in this space.

In the computer networking discipline, there have been few attempts at automatic assessment of laboratory work. One such system has been developed by (de la Oliva, Bernardos, & Durán, 2012). In this system, a series of predefined tests are automatically applied to the student's solution of the exercise. The results of these tests can be used for the purposes of validation and provision of feedback. However, it is difficult to generate meaningful feedback from validation testing as the output is often restricted to aspects of functionality. Ideally, we would like a solution that can analyse student work to determine what is wrong rather than what did or did not work correctly.

The approach we take in this paper is to provide a mechanism which can automatically generate feedback. Once this mechanism is developed, it can be deployed to asynchronously assess student work and to provide timely, formative feedback.

Assessment of Skills Exams

At Swinburne University, we expect our students to acquire competency in practical skills as well as theory. As such, many Units run dual examinations, 1) a written exam to assess the students' theoretical knowledge; and 2) a skills exam to assess the students' practical skills.

Lab Environment

The networking laboratory classes at Swinburne University are well equipped. There are two networking laboratories – located in adjacent classrooms – each containing 100 Cisco Routers and 100 Cisco Switches. For teaching purposes, this equipment is arranged into 25 kits, each containing four routers and four switches. The kits are located in five equipment enclosures spaced throughout the room with five kits per enclosure. Each enclosure/kit is colour-coded and is managed and accessed via a purpose-built web site that provides facilities for equipment booking and device access. This configuration is duplicated in the second lab for a total of ten enclosures and fifty kits (Klimovski, Cricenti, & But, 2011).

Skills Exams

The Skills Exams are designed to assess the students' capacity to complete network design and implementation tasks under examination conditions. Our extensive lab facilities allow us to schedule exams for up to fifty students at any one sitting. However, with large student numbers it can be challenging to run and assess these exams. At lower level Units, students are typically given two attempts to prove their abilities, while more advanced classes only provide students with a single attempt. Exam durations and complexities are:

- **Introductory Unit** – one hour exam to build a small 3 device network with two attempts, there are typically 220 students per semester, twice a year
- **Intermediate Unit** – two hour exam to build a more complex 4 device network with two attempts, there are typically 80 students per semester, twice a year
- **Advanced Units** – three hour exam to build a complex network containing up to 7 devices with a single attempt. There are four such Units, each with an average of 40 students per semester, twice a year

As is evident from the numbers above, it is a complex task to schedule and execute these Exams, let alone complete the associated assessment tasks. Faced with between 500-600 Skills Exams every semester, we chose to develop a system to automate the collection and assessment of as many of these tasks as possible.

Swinburne University – Skills Examinations Automated Assessment Tool

When designing the exam assessment system, a number of requirements were considered:

- **Auditability** – Student work needs to be collected and stored for later re-assessment in case a review is requested or a complaint needs to be investigated
- **Scalability** – Due to the sheer numbers of exams that need to be run, the turn-around time between exams needs to be minimised. In order to complete all exams within a single day for our Introductory/Intermediate Units, it is necessary to reset the room for the next exam within 50 minutes of completion. This requires the system to fetch and download student work for all fifty students across potentially all 400 devices, and reset all those devices to a clean state within no more than ten minutes so as to allow the remaining preparation tasks to be completed
- **Flexibility** – Exam collection is used across all Units, automated assessment is only used for the Introductory and Intermediate Units. However, the system is designed to be extendable to more advanced Units through the addition of

modules to assess

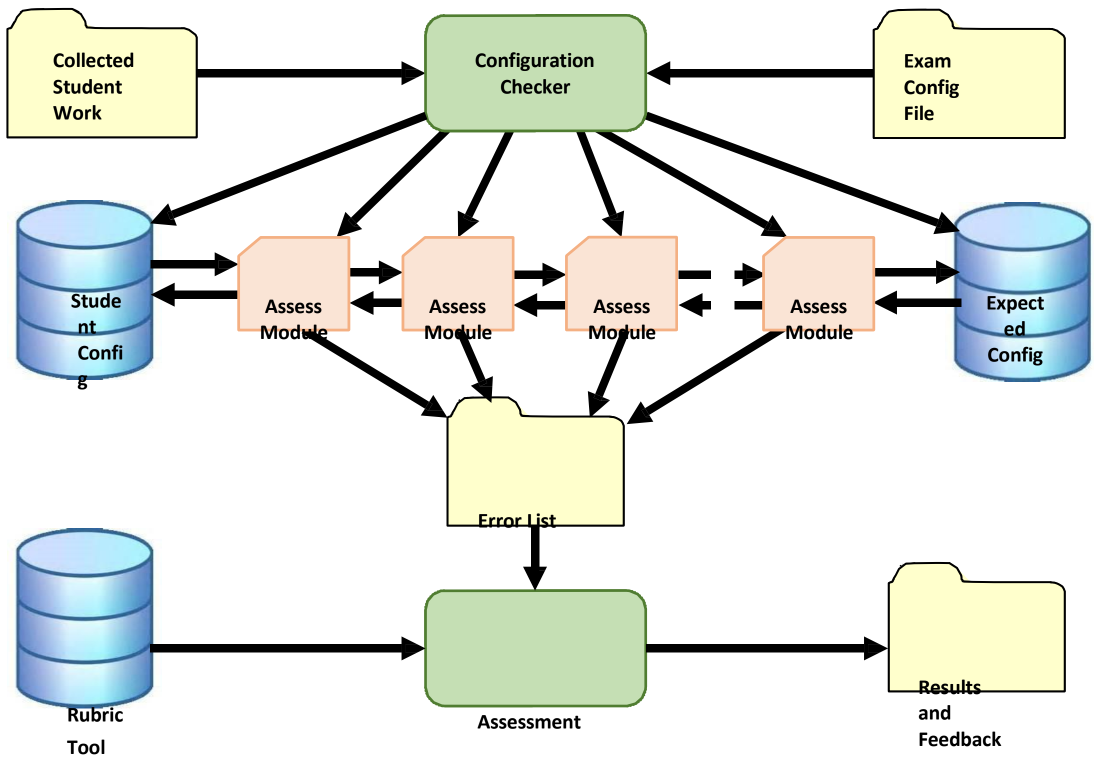
Collected Student Work
Configuration Checker
Exam Config File
Stude nt Confi g
Assess Module
Assess Module
Assess Module
Assess Module
Expect ed Config
Error List
Rubric Tool
Assessment
Results and Feedback

Figure 1: Automated Assessment Tool Architecture Diagram

configurations currently not supported. The system has also been designed to allow the examination parameters to be modified without re-coding any software

- **Re-assessability** – The modular design of the assessment system means collected student work can be re-assessed if necessary. Further, the assessment system has been designed to support multiple assessment rubrics for different Units
- **Student Feedback** – We aim to generate personalised, human-readable feedback specifying what the student did incorrectly. This can then be used by students to improve their understanding of their mistakes

The primary components of the assessment tool are modular in nature, as shown in Figure 1. Exam collection is separated from assessment, which is further separated from other tasks such as generating results, uploading results to a central repository, and disseminating feedback. This design allows for re-purposing of the modules for different Units, for example in Advanced Units to collect student exams without assessing them.

As per Figure 1, collected student work is loaded from stored files and parsed to generate a database representing the student configuration. These files contain the directly captured output of executing a series of specified commands on the network devices. Similarly, an exam configuration file containing the expected exam solution is loaded and parsed to generate a database containing the expected configuration. The exam configuration file is written as an INI configuration file where individual lines specify a required configuration.

The configuration checking tool will then execute a series of modules using these two databases as input. Each module will assess a certain aspect of the student configuration against the expected configuration and generate a list of detected errors made by the student. The errors generated by all the modules are collated and output to an error file. This file contains a classification and a description of the error.

Finally, the assessment tool will load the list of errors and apply a rubric as specified by the Unit Convenor. The rubric will determine the final mark based on the error classifications in the error file. This tool will generate an output file containing both the final result and feedback that can be provided back to the student on their performance. This file is later disseminated using other components of the assessment system.

Student Feedback

Our assessment tool was designed to provide personalised feedback to the students. Prior to its deployment, exams were assessed by Academic Staff. Following the first of two exam attempts, a generic email was sent to all students incorporating a list of common mistakes made by all students. The intent was to allow students who failed to see what mistakes had been made, and to try to identify their mistakes within that list.

This approach was problematic. Feedback was general in nature and students who failed were typically not able to determine which parts of this feedback applied to them. Further, due to the rushed nature of assessment, personalised feedback was never possible as examiners stopped noting errors once it became apparent that a student had failed.

Following the deployment of automated assessment, we were able to provide a personalised list of mistakes to students following their first attempt at the exam. Figure 2 provides some examples of this feedback. These are typical of the comments that an instructor might provide in class as feedback to help the student understand what was broken and lead them to consider how they might fix that error going forwards.

We are able to achieve this detailed type of feedback as we parse the captured output of the network devices to determine what the student actually did or did not achieve. This approach allows us to infer the reasons behind non-functionality of the network, something that is difficult to achieve if just running connectivity tests.

Proposed Online Lab Feedback Tool

We have successfully deployed a system to assess student work in summative end-of- semester practical skills exams in a number of networking Units. This tool has now been used over a period of six years to assess exams. As well as marking exams, this tool provides personalised feedback to students regarding their exam performance.

One of the key design features of this system is flexibility, whereby the required exam configurations are specified using a configuration file. This feature allows development of new exam papers with no programming effort.

Due to the nature of exams, this tool is currently only available on a secure system where there is no student access. We propose to open up portions of this tool to student access in order to provide an innovative system to aid in remote/blended learning environments, and to provide an extension to the in-lab environment for students wishing to do further study.

Virtual Lab Supervisor

Because our exam assessment tool already generates formative-type feedback, we believe that it can be used to address the issue of lack of immediate, formative feedback in a blended learning context. This addresses the concerns raised by (Nicol & MacFarlane-Dick, 2006). Allowing students to directly access the assessment tool will in effect provide them with 24/7 access to a Virtual Lab Supervisor that will be able to provide them with the formative feedback necessary to help them guide their own learning.

The existing tool suite is already able to:

- Collect configuration information from a number of physical devices in the lab
- Assess collected configurations against a flexible set of pre-determined tasks
- Generate formative feedback on those configurations in a manner that can be directly used to enhance learning and understanding by our students.

```
You have committed one or more major errors that will cause your network (or
parts of your network) not to work.
Details of your error(s) are listed below:

Switchport is not configured in "trunking" mode
  SwitchA(FastEthernet0/11)

Required VLANs not being trunked
  SwitchA(FastEthernet0/1): VLANs (354) not being
  trunked SwitchB(FastEthernet0/1): VLANs (354) not
  being trunked

Following trunk interface(s) configured with an IP address when it should have
sub-interface addresses only
  Switch Trunk Link (RouterA: FastEthernet0/1): You configured (192.168.1.193/27)

No IP Addresses configured for the following interfaces
  Sub-interface for VLAN 1 (RouterA:
  FastEthernet0/1.1):

At least one default static gateway/route has the incorrect next hop or exit
interface programmed
  RouterB: Default gateway/route via Serial0/0/0

The following networks are not being advertised when they should be
  RouterA(Serial0/0/0) using protocol ospf

You have committed one or more minor errors. This type of error will not on
its own cause your network to fail, but may impact on your final result.
Details of your error(s) are listed below:

No default gateway has been programmed on the switch (when there should be)
  SwitchA

Unnecessary VLAN Created
  SwitchB: VLAN(352:management) has been created when it should not have been

The following networks are being advertised when they should not be
  RouterA(FastEthernet0/1) using protocol ospf

The following routing protocol "network" statements do not advertise any
interfaces on the corresponding router
  RouterA(ospf):  network 192.168.1.244 0.0.0.3 area 0
  RouterB(ospf):  network 192.168.1.129 0.0.0.0 area 0

Incorrect network address/mask allocated for the following networks
  VLAN 15 Web Server (RouterB: Loopback0): Configured (150.0.0.1/32) where the
expected network is (121.0.0.15/32)
```

Figure 2: Sample feedback output of automated assessment tool

We would like to extend our assessment tool with a web-based frontend to act as a Virtual Lab Supervisor with the following features:

- Provide a blended environment via direct student access such that it can be used outside the supervised classroom
- Academic staff can upload expected configurations for certain laboratory and/or learning tasks
- Students can assess their lab configurations against the uploaded solutions and receive personalised formative feedback on their progress in achieving these tasks.

We also plan to expand the existing management system to allow remote access to network device management and configuration. Students will then be able to build and configure networks remotely and use our Virtual Lab Supervisor tool to obtain feedback on their efforts.

In order to prove the viability of this approach, we have extracted a small portion of the assessment tool that assesses the functionality of firewall rules, and created a small web- based tool allowing users to submit firewall rule sets for feedback. This semester, testing is being undertaken by teaching staff with an aim to making it available to students next year. Initial feedback is that the tool functionality is similar to comments that supervisors might make to students regarding similar problems attempted in the lab environment.

Expected Outcomes

Our primary aim is to improve student learning outcomes, ultimately leading to improved results for all students undertaking these Units.

Even in a traditional setting, students would not always get immediate access to a Lab Supervisor. Access to a Virtual Lab Supervisor for formative feedback purposes would increase the effective lab time for individual students, both within normal teaching hours and for after-hours instruction.

Access to such a tool will also allow students who are unable to attend certain face-to-face classes, or unable to complete associated tasks within the allocated class time, to be able to complete the work in their own time and still be provided with constructive feedback

We also expect Academic Staff to start developing extended Lab Exercises that would not typically be completed within the normal weekly lab class. These exercises would be designed to reinforce learning undertaken in existing lab tasks, and be undertaken as further study by students with feedback provided by the Virtual Lab Supervisor.

We hope that offline access to feedback will also increase class participation and lead to more meaningful discussions, both within the Blackboard online discussion forums and within the classroom as students have greater exposure to learning materials and feedback.

Proposed future developments allowing students to create their own exercises will allow advanced students to set challenges and essentially run their own practice Skills Exams to aid them in preparation for the actual summative assessments.

In summary, we see the proposed tool as an ideal means of implementing a blended learning environment. This would augment rather than supplant existing teaching techniques, providing students with true 24/7 access to teaching resources and immediate formative feedback without having to staff teaching resources on a 24/7 basis.

Concerns

The existing exam assessment tool is both functional and well-tested to ensure functionality. However usage is restricted to teaching staff. Any plans to open this system up to general access by students leads to a number of concerns that need to be addressed. These include:

- **Security/privacy** – Student submissions and feedback must be inaccessible by other students. Students cannot initiate testing to receive feedback of others work
- **Protection of exam assessment tools** – As certain parts of the system are used for examination purposes, it is essential that this code be protected from tampering
- **Access Priorities** – If opening access to the lab for off-campus based students, a solution needs to be found to ensure fairness between off-campus and on-campus students. Special consideration must be considered for providing access to on- campus students when a scheduled lab class is running

- **Academic Integrity** – Academic Integrity is particularly important in the context of summative assessment. The role of a lab supervisor is to aid in student learning, as such, the goal of the Virtual Lab Supervisor is to provide formative feedback

(But & Shobbrook, 2012) have previously demonstrated that providing Lecture Recordings can often lead to degraded academic outcomes. Providing after-hours access to lab facilities and a Virtual Lab Supervisor for feedback purposes is not the same as recording a lecture presentation. However, it will be interesting to observe if the increased availability of an alternative learning environment will lead to similar outcomes.

It will be incumbent on Academic staff to observe whether poorer performing students convince themselves that they will benefit from this tool and therefore not attend scheduled lab classes, only to not then engage with the curriculum due to non-attendance. We believe that this is an open-ended question that all educators need to keep in mind when considering Blended Learning of all flavours.

Conclusions

Modern pedagogy is driving the deployment of Blended Learning techniques. One of the more challenging aspects of blending an Engineering education is that of moving hands-on laboratory tasks to an online environment. The absence of trained Lab Supervisors on a 24/7 basis can impact on students learning outside of the classroom.

At Swinburne University, we assess student learning in our computer networking Units via Skills Exams and written exams. We have developed an automated assessment tool that is able to collect and assess student work. As the tool does not perform functionality tests, we are able to prepare personalised feedback on what was done incorrectly.

We propose to extend this automated assessment tool to provide functionality akin to a Virtual Lab Supervisor. By allowing students to remotely access our labs, the Virtual Lab Supervisor will then be able to examine student work and provide formative feedback in near-realtime.

We anticipate that our eventual system will provide a more flexible learning environment for students:

- Students will be able to undertake laboratory exercises in their own time, and still be provided with constructive feedback.
- Students who wish to extend themselves by undertaking their own challenges, will be able to devise tasks and assess their performance against this criteria.

A successful deployment of this tool would provide a base for other Engineering disciplines to construct practical remote learning environments, and remove one of the many challenges facing the Engineering education community in the global move to Blended Learning.

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