An Automated Support System in a Remote Laboratory in the Context of Online Learning

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Abstract. Remote engineering and science laboratories are gaining an increased prominence due to its versatility, ease of use 24/7, most likely open and shared access to any components, setups and instruments, in reconﬁgurable circuits, and laboratory establishments, including quite unique and expensive ones. The remote laboratories are increasingly shared nationally and internationally mainly with a free access or less so in a pay-for-fee use. Due to the universal time-wise access, human tutoring in remote laboratories, especially synchronous is not realistic. Therefore, an automated support for the students practicing the remote experiments, missing a human tutor is being developed. The system analyses common students’ mistakes in the remote laboratory and identiﬁes remedial actions. Students are informed about their mistakes, extracted from learning analytics of the remote laboratory, in order to correct and revoke their actions. The paper reports on learning habits of the students, their backgrounds and their perception of online learning preceding and following the use of the automated tutoring system.

Keywords: Remote laboratory · NetLab · Tutoring system · Learning analytics

1 Introduction

The remote laboratory NetLab at the University of South Australia allows students to remotely perform fundamental electrical engineering, electrical circuit theory and signals and systems experiments. The remote laboratory has accommodated many thousands of learners over the years, since its introduction in 2002 and provides a secure learning collaborative environment in a potentially multinational setting, leading to independent learning in communities of practice.

The remote laboratories in the context of the coronavirus pandemic are more relevant than ever. The international and often shared use of remote laboratories is advancing rapidly and is very likely to escalate. Remote laboratories present unique benefits, but typically do not have a human tutor present to assist students. Work on tutoring systems has been ongoing for some years, providing a means of supporting students with less involvement from a human tutor.

In our work, we are adding a tutoring system to a remote laboratory system to better assist students. The remote laboratory NetLab is a collaborative laboratory, where all logged in users have a real time input in laboratory actions and view of what other users
on the system are doing. This was originally designed so that students could work together in a group, or that a human tutor could be present to assist students. However, employing a staff of human tutors to remain logged into the system 24/7 to assist students would be unrealistic.

The goal of the study is to augment human tutors with an automated tutoring system (ATS) that can alert students to mistakes in their laboratory work, or to any significant differences between their measured results and how their circuit would be expected to behave based on relevant background theory. We do not fully expect the support system to completely replace human assistance but will measure how much students use the automated system and assess student behaviour to identify any changes in their learning process based on feedback from the automated student support system.

In the first stage of the study, student usage of the remote laboratory was examined. All student actions on the system were recorded, and from these action logs it was possible to identify common student errors. Mapping of successful and erroneous actions were systematically analysed [15]. Additionally, the practical reports submitted by students provided a way to identify any mistakes that the students made and did not rectify before submitting their work.

2 Literature Review

Remote laboratories (RL) have long been used in modern higher education. They are most often part of educational programs in the field of engineering [1–6]. Remote laboratories are a method of class placement between the computer simulation experiment and the manual implementation of a practical task. They replace the manual implementation (e.g. connecting circuits using standard connectors) of a task for a remote one, consisting of manipulating connections on a real equipment using IT tools and specialised switching devices [7].

Thanks to the development of technology in recent years, RLs are developed extremely quickly. They are based on modern solutions straight from Industry 4.0 and use the increasingly available Internet of Things (IoT) technologies [8]. These technologies replace dedicated and closed solutions in the process monitoring and process automation [1]. Modern software systems, such as MediaWiki [5] or Augmented Reality techniques [6] are also used.

RLs are created and developed as university projects [7], and now, due to the availability of technology, more and more often as rudimentary student projects in cooperation with experienced lecturers [1].

The impact of RL on study results has been studied many times. It can be observed that the attitude of students to RL changes with the civilisation changes occurring with the development and dissemination of digital technologies [4]. Students are currently people who have been using digital technologies in everyday life from an early childhood. For this part of society, the virtual world becomes part of the real world. Virtualisation of processes, including didactic aspects, is an everyday experience for them.

For example, in [2] the results of a three-year experiment assessing the impact of RLs on learning outcomes are presented. The results of examinations of three student
groups using the control systems laboratory were compared: only physical, physical with additional optional RL and only RL. Comparison of survey results showed great interest in RL of the students. Analysis of exam results showed that the use of RL has a positive impact on the level of achievement of learning outcomes [2].

Despite the positive results of the research, students’ attitudes to RL and the impact of their use on learning progress of the RL defect in relation to real laboratories, the disadvantages of RL are obvious. On the one hand, there is virtualisation of environments - the student does not have direct contact with the equipment in a simulated environment, but in RL the students deal with real equipment. On the other hand, there is also no contact with the academic teacher – the tutor. This contact is an indispensable element of university education, although it is changing in the era of the coronavirus.

In RL, various systems are used to support their use - from simple reservation and access systems [10] to Learning Management Systems (LMS) [11]. LMS for RLs are created as dedicated systems [12] or existing LMS are used through their integration with RL [11–13]. LMS in RLs offer a variety of functionalities, such as registration and collection of data on completed experiments (including erroneous and correct student activities), evaluation of learning outcomes, student surveys and wide possibilities of data mining with learning analytics tools [14].

3 The Remote Laboratory NetLab

The remote laboratory NetLab provides users with access to real electrical components which can be remotely controlled. Students can use the system to build circuits, experiment with different input signals and measure the output signals. These experiments can be done at any time and in any place, with the Internet access and students are given the opportunity to try many different values of real components, input signals in the circuit and view the effect.

The remote laboratory includes a function generator, a digital multimeter and a four-channel digital storage oscilloscope, all of which can be completely controlled by students as they carry out experiments. A camera provides a live image of the system, showing students that they are obtaining measurements from a real circuit, not from a simulated one. Fig. 1. Shows what students will see when using the oscilloscope to observe the behaviour of a series RLC circuit.

The client used by students/users also includes a text chat area for discussion with assignment group partners, and with the tutoring system (the lower left). The system is collaborative with up to 3 students being given access to the system at one time, and because all students are controlling the same system a list of actions is provided at the lower right of the window. This allows the students who are working together to see what their collaborators are currently doing, as they would be able to do sitting side by side in an in-person laboratory. These actions are recorded for later review in the system action log.
Technically, more than three students would be able to use the RL, but from experience, it may create conflicts of controlling the RL elements simultaneously.

Circuits built using the remote laboratory can include any combination of 4 resistors, 2 capacitors, an inductor and the measuring instruments available. All passive components are variable, and each can be set to any of 10,000 different values. Circuits are built by dragging and dropping components in the Circuit Builder window, and then connecting terminals by the click of a mouse. Result is shown in Fig. 2. The circuit built in the screenshot is a series RLC circuit, with the function generator supplying a variable frequency input, and the oscilloscope measuring the voltages at all circuit nodes. Unused components are shown on the right-hand side.

We have shown in previous published research [15] that student errors in the remote laboratory are highly repetitive and consist of the same specific errors repeated over and over. This suggests that an automated tutoring system can be of assistance.
4 ATS and Student Responses to Online Learning

Technical Details
The automated tutoring system (ATS) consists of two key components – a problem identification module, and a chat engine module. The problem identification module has a set of rules, based on past student mistakes, that allow it to recognise common problems. These common problems include wiring issues, such as short circuited components, or incorrectly connected oscilloscope signal and ground wires. The problem identification module can also recognise common oscilloscope misconfigurations, and warn students. Understanding triggering in particular can be a problem for students, and the system is able to recognise trigger conditions that the student’s circuit is unable to ever produce. The problem identification module also constantly compares the measured results students are receiving from real equipment with results from a simulated model of the remote laboratory hardware. This comparison can identify further issues, such as an overloaded function generator, or incorrect oscilloscope configuration which prevents accurate measurements from being taken.

The chat engine module is responsible for all communication with the student, using the instant text messaging tool built in to the remote laboratory software. On the first login of a particular student, the chat engine introduces itself to the student, and explains how it can be asked questions. The chat engine module monitors flags that are set and cleared by the problem identification module. A unique flag is set for each particular error that the problem identifier can recognise, and another flag is set if a student makes a mistake and does not correct it within a timeout period of 2 min. If a student does not fix the mistake, the system will warn them that there is an issue they need to fix, and offer help in diagnosing the problem.
The system does not immediately tell students what problem is present – some students prefer to find issues for themselves. Those who would like assistance can ask what is wrong with their circuit, and will be given a list of what needs to be fixed.

The chat engine script has been designed to be somewhat playful, the aim being to make the tutoring system helpful during the experiment, and an amusing distraction afterwards. If someone says hello to the robot, it will greet them back. If the chat engine is unable to find an appropriate reply for a message from a student, it will initially apologise for not being able to answer. In situations where it is unable to answer several questions in a row, it will start replying with deliberately silly phrases.

**Student Responses**

A group of Master of IT full-time students from the Lublin University of Technology (LUT) in Poland were enrolled in their final semester in a course delivered in 2020 in English by Australian academics, called Monographic Lecture on Remote laboratories. For assessment the students had to conduct an experiment on a RC circuit using the remote laboratory NetLab and write a laboratory report in English. The lectures and the experiment were intended to introduce them to remote laboratories and give them a taste of working in one, rather than testing their circuit theory knowledge. Second year undergraduate electrical and electronic engineering students at the University of South Australia (UniSA) in Australia were also asked to conduct two experiments using the remote laboratory NetLab, and submit their laboratory reports. The students from both institutions were surveyed twice, before and after the remote experiment.

The first survey assessed the LUT students’ starting point, including questions on their device usage and study habits, questions on what circuit building methods they had used before, and a short theory skills test. Responses indicated that in extreme cases the students spend some 60–70 h on the Internet and only about half of the time is study related. The Masters students’ theoretical knowledge related to circuit theory and electronic instrumentation was sketchy, which is not surprising as they had those topics early in their undergraduate degree some 5 years earlier. The undergraduate UniSA students fared somewhat better in the initial skills test, but had difficulty with questions on oscilloscope triggering.

The post-experiment survey demonstrated that the Masters students improved their knowledge regarding circuit theory and understandings real instruments and components – 71% yes. Before the era of coronavirus only 7.9% of them studied online. If they had a choice, now 86% of them would prefer to study online. Some students commented that 100% of laboratories could be online. The Automated Student Support System was used by 43% of the students and of those 64% stated that it helped them to alert to circuit problems in their wiring and instrumentation setup.

Stated advantages of studying online are that the students do not need to wake up early, do not need to travel and can make study more economical, can study while at work, replaying of recorded of online sessions allows for deeper learning. The statement that teaching online is comparable with face-to-face in terms of learning outcomes was supported by 57% of the Masters students (agree and strongly agree on the Likert scale), preference of either mode of delivery was indicated by 38%.

The undergraduate students from UniSA who responded to the survey were less enthusiastic about online study, with only 13% showing an interest in further online
study. This may be a protest response by the on-campus students, who mostly had not studied online before, but who had all of their study moved online suddenly in week 4 of a 13 week study period in 2020 due to the coronavirus.

The undergraduate students responded positively to the remote laboratory. When asked to rank their preferred method of conducting practicals, 80% of students put hands-on practicals in a laboratory first. However, all students ranked remote laboratories ahead of software only simulation. They appreciated the understanding of the imperfection of real electrical components that the remote laboratory gave them. They also liked being able to conduct experiments from home, and being able to easily repeat an experiment if they were unsure of their results from the first attempt. Some did ask for an alternative to turning dials to set values, preferring the option of typing in values.

The tutoring system received mixed evaluations. An issue in the model of the remote laboratory used by the problem identification module to verify results caused the tutoring system to warn some students of possible errors in measurements that were correct. These students contacted their human tutor for verification. In the survey, students responded that the erroneous error messages made them spend extra time double checking their results – which produced very good results for their practical reports, but lead to some frustration. Students did like the idea of an automated tutoring system to find problems early, and several enjoyed the way that the chat engine spoke. When asked what they liked about the tutoring system, one student responded “it was cheeky”. Instances can be seen in the chat logs of the system of students testing the system to see how it will reply to various nonsense messages – some light hearted moments in a stressful world.

**Impact of Automated Tutoring System**

A comparison of UniSA student assignments shows some improvement between 2018 cohorts, who did not use the tutoring system, and the 2020 cohort who did. The students were asked to complete very similar assignments, the only difference being the removal of a simple simulation task for the 2020 cohort, and slight changes to the component values that students were asked to use in order to prevent plagiarism from the previous cohort. With the same marker applying identical marking criteria to both groups, the mean mark for 2018 students who submitted their practical report was 75.21% (59 students). For 2020 students, the mean practical report mark was 86.48% (54 students). Several of the 2018 reports contained mistakes that the tutoring system is able to detect, but none of the 2020 submissions contained these errors.

An analysis of system action logs between 2017 and 2020 was performed using an automated analysis script. During this time, 2386 human logins and 2080 experiment sessions were recorded. The system without any student support system in place was used in 2017, 2018 and 2019. In 2020, the automated tutoring system was put in place.

Each experiment log was checked by the analysis for circuit and oscilloscope configuration errors, using the problem identification code from the tutoring system. The script counted how many changes to the circuit were made by students between an incorrect circuit being built and a correct circuit being built. When the script detected an invalid oscilloscope configuration, it counted the number of oscilloscope settings changed by the students before correctly configuring the oscilloscope again. Finally, the analysis script also counted the number of experiment sessions that ended with an
incorrect configuration – typically, a student’s last action should be to obtain measurements from a valid circuit before logging out (Table 1).

| Year | Logins | Oscilloscope corrections | Circuit corrections | Experiments ended with errors |
|------|--------|--------------------------|---------------------|-----------------------------|
| 2017 | 289    | 5374                     | 55                  | 82                          |
| 2018 | 662    | 9044                     | 59                  | 158                         |
| 2019 | 795    | 9303                     | 60                  | 157                         |
| 2020 | 640    | 8218                     | 189                 | 7                           |

Comparing the two years of students surveyed and graded on the same exercise (2018 and 2020), it can be seen that a similar number of students logged in to the remote laboratory. With the automated tutoring system, students still took approximately the same number of steps to correctly configure the oscilloscope. More circuit corrections were needed in 2020, but a manual analysis of logs shows that most of these incorrect circuits were cases of students temporarily disconnecting components to measure their values with a multimeter, resulting in circuits that cause incorrect (but irrelevant) oscilloscope readings.

Most significantly, far more experiment sessions ended successfully. In 2018, 158 experiment sessions ended with a student having left the oscilloscope or circuit configured incorrectly. Some of these students exceeded their booked time on the system and were disconnected in the middle of an experiment, while others simply logged out without fixing the problem. In 2020 with the automated tutoring system in place, only 7 experiment sessions ended with a circuit or oscilloscope configuration that could not give valid results.

5 Conclusions

In 2020 evaluation 95% of Lublin students indicated that online teaching is a preferred delivery or had no preference which method of delivery is offered. This is another convincing learning paradigm preference shift toward the online teaching and learning including remote laboratories.

The automated tutoring system did not change the average number of steps taken by students trying to fix a given problem with their circuit. Future work could increase the detail provided to students when they are warned about an issue, with more specific advice on fixing an issue. However, it can be seen from the action logs and submitted practical reports that significant goals have been achieved. The automated tutoring system ensured that all students were aware of any mistakes that they had made in the circuit wiring or oscilloscope settings, and could correct these while conducting their experiment, rather than realising that they had made a mistake when reading their manually marked practical report several weeks later.
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