Enhancing Engineering Education through Remote Laboratories

by

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I am the author of the thesis entitled

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Abstract

This document will outline the research completed in order to determine the engagement levels and learning experience of students in a unique remote laboratory for electrical engineering students. The aim of this research was to establish a method of remotely presenting students with easily accessible real time outputs of a currently functional solar inverter, displaying the energy and power generated to the students, as well as all logged data of the daily summaries going as far back as 2013. The laboratory was viewed a total of 558 times between 12th of July 2016 and the 28th of February 2017, with a majority being in the November to January period.

Participants were selected based off the subjects they were currently enrolled in, as the laboratory was set up as an additional resource in many different classes. Four different subjects were selected, ranging from undergraduate second year classes to postgraduate classes. Once students had completed their assessments, they were invited to complete a survey on their laboratory experiences, with a total of 34 students responding. This was unexpected, as data on student behaviour in the laboratory was also tracked, with the laboratory being accessed over 500 times during the duration.

A preliminary study on students’ willingness to partake in remote education was undertaken, showing that when presented with the opportunity to use remote education as a studying tool, students opted to use this method. Primary analysis of these results was taken from observing student participation
in class compared to online resources, were a vast majority of students opted to a remote education even with in person practical classes offered.

Research aimed to analyse how students accessed the remote laboratory, using both students’ written feedback and google analytics to gather this information. This study focused on observing students access times and number of returning visits. It was also determined what devices were used, as well as what operating systems and web browsers, finding a majority of the students used Macintosh devices and Google Chrome, and also that only 27% of views were returning visitors. Analysis of these results was done using data gained from google analytics, such as exact access numbers and logs of information provided by students accessing the laboratory.

After this, an analysis of the perceived learning objective for the laboratory was completed. It has been observed that different educational media invite students to approach their learning experience with different perceived laboratory focuses, and the perceived focus of this laboratory was analysed. This was done using students written responses to a survey as well as gaining numerical data from a likert scale. It was found that students would have preferred more control of the hardware as a primary improvement, and that the perceived learning objective was primarily ‘Signal Analysis’ followed closely by ‘General Engineering Principals’. Analysis of these results was done primarily by grouping written responses together to see the total trend of responses, and likert scales were compared together via converting each likert scale into a weighted response and comparing these numbers.
Finally, students’ belief in the validity of the data was analysed, as well as their belief in the realism of the equipment, as well as their feeling of presence when completing the laboratory. This data was gained by observing responses to a survey completed after the assessments of all classes. Results indicate that a majority of the students had little issue accessing the laboratory, but accessed the data very few times. They trusted the validity of the data being displayed to them, with 61% believing the data presented was from a real system instead of a computer simulation. This did not create a strong feeling of presence, with 75% of students falling between agree and disagree when asked questions such as “I felt like I was physically in the environment logging data”.

After presenting these results, a discussion and comparison to previous literature is undertaken, comparing perceived learning objectives to other laboratories used in engineering education. An analysis of this laboratory’s place in undergraduate education is also completed, with the undergraduate engineering accreditation requirements being analysed with respect to this laboratory.
Table of Contents

1. Introduction..............................................................................................................14

1.1. Aim, Objectives and Research Question......................................................19
  1.1.1. Aim....................................................................................................................21

  1.1.2. Objectives ......................................................................................................22

  1.1.3. Conclusion ....................................................................................................23

2. Literature Review ...................................................................................................26

  2.1. Clark Kozma debate .......................................................................................29

  2.2. Remote education ............................................................................................35
    2.2.1. Computer Simulations .............................................................................41

    2.2.2. Remote laboratories ................................................................................44

  2.3. Presence ...........................................................................................................50

  2.4. Student learning ................................................................................................53

3. Design goals .............................................................................................................60

  3.1. Requirements of remote laboratory ...............................................................60

  3.2. Realism in remote laboratory .........................................................................62

  3.3. Student access of remote laboratory ...............................................................63
    3.3.1. Access without installs .............................................................................65

  3.4. Hardware Requirements ..................................................................................65
    3.4.1. Requirements of working with this hardware ..............................................65

    3.4.2. Required hardware to be purchased ..........................................................66

  3.5. Software Requirements ....................................................................................66
    3.5.1. Operating system considerations ...............................................................67
3.5.2. User Download/bandwidth considerations ..........................67

4. Methodology - Research foundation and laboratory design ................69

4.1. Overview of project preparation ........................................69
  4.1.1. Research foundation ..................................................70
  4.1.2. Literature review ......................................................70
  4.1.3. Attend Collegiums ....................................................71
  4.1.4. Possible future work ..................................................71

4.2. Laboratory Knowledge Foundation ........................................71
  4.2.1. Testing remote laboratories .........................................71

4.3. Laboratory Design ..........................................................72
  4.3.1. Analysis of current software packages .............................74
  4.3.2. Determine exact requirements of the laboratory .................76

4.4. Laboratory Building ........................................................76
  4.4.1. Analysis of currently available hardware .........................76
  4.4.2. Analysis of the requirements for conversion to remote laboratory

4.4.3. Lab access without installs ..........................................78

4.5. Identifying research participants .........................................84

4.6. Gathering and analysing results .......................................85

5. Methodology - Survey and questionnaire .................................86

5.1. Ethics training ..............................................................87
  5.1.1. General training .......................................................88
  5.1.2. Human research .......................................................88
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1.3.</td>
<td>Ethics application</td>
<td>88</td>
</tr>
<tr>
<td>5.2.</td>
<td>Survey Design and question selection</td>
<td>89</td>
</tr>
<tr>
<td>5.3.</td>
<td>Gathering Survey Data</td>
<td>93</td>
</tr>
<tr>
<td>5.3.1.</td>
<td>Identifying Research Participants</td>
<td>93</td>
</tr>
<tr>
<td>5.3.2.</td>
<td>Gathering Survey Responses</td>
<td>99</td>
</tr>
<tr>
<td>5.4.</td>
<td>Gathering user behaviour data</td>
<td>103</td>
</tr>
<tr>
<td>5.4.1.</td>
<td>Google analytics</td>
<td>104</td>
</tr>
<tr>
<td>6.</td>
<td>On campus students’ willingness to adopt remote education</td>
<td>109</td>
</tr>
<tr>
<td>6.1.</td>
<td>Publications</td>
<td>109</td>
</tr>
<tr>
<td>6.2.</td>
<td>Introduction</td>
<td>109</td>
</tr>
<tr>
<td>6.3.</td>
<td>Subject background</td>
<td>111</td>
</tr>
<tr>
<td>6.4.</td>
<td>Practical session overview</td>
<td>111</td>
</tr>
<tr>
<td>6.5.</td>
<td>Student access to practical content</td>
<td>113</td>
</tr>
<tr>
<td>6.6.</td>
<td>Recording the sessions</td>
<td>113</td>
</tr>
<tr>
<td>6.6.1.</td>
<td>Camera Setup</td>
<td>114</td>
</tr>
<tr>
<td>6.6.2.</td>
<td>Editing</td>
<td>116</td>
</tr>
<tr>
<td>6.7.</td>
<td>Student behaviour with extra content</td>
<td>116</td>
</tr>
<tr>
<td>6.8.</td>
<td>Discussion</td>
<td>117</td>
</tr>
<tr>
<td>6.9.</td>
<td>Conclusion</td>
<td>117</td>
</tr>
<tr>
<td>7.</td>
<td>Results – Students’ Engagement of Real World Remote Laboratory</td>
<td>118</td>
</tr>
<tr>
<td>7.1.</td>
<td>Publications</td>
<td>118</td>
</tr>
<tr>
<td>7.2.</td>
<td>Introduction</td>
<td>118</td>
</tr>
<tr>
<td>7.3.</td>
<td>Challenges of the remote laboratory</td>
<td>120</td>
</tr>
<tr>
<td>7.4.</td>
<td>Remote Laboratory Design</td>
<td>122</td>
</tr>
<tr>
<td>7.4.1.</td>
<td>Inverter communication architecture</td>
<td>123</td>
</tr>
<tr>
<td>7.4.2.</td>
<td>Server Side Architecture</td>
<td>128</td>
</tr>
<tr>
<td>7.4.3.</td>
<td>Web layout</td>
<td>131</td>
</tr>
</tbody>
</table>
7.4.4. Limitations of this design .................................................................137

7.5. Students accessing the laboratory ..................................................139
  7.5.1. Student devices used to access laboratory .....................................141
  7.5.2. Student access over time .............................................................144

7.6. Discussion .......................................................................................145
  7.6.1. Suggestions for future research ..................................................152

7.7. Conclusion .....................................................................................152

8. Results – Students’ Perceived Learning Focus .................................154
  8.1. Publications ....................................................................................154
  8.2. Introduction ....................................................................................154
  8.3. Laboratory overview ......................................................................156
  8.4. Case study Outline ........................................................................160
  8.5. Student responses ..........................................................................162
  8.6. Discussion .......................................................................................174
  8.7. Conclusion .....................................................................................180

9. Results - Student’s belief of reality, validity of data and presence ....182
  9.1. Publications ....................................................................................182
  9.2. Introduction ....................................................................................182
  9.3. Survey setup ...................................................................................185
  9.4. Students accessing Laboratory ......................................................185
    9.4.1. Survey structure ........................................................................189
  9.5. Student responses ..........................................................................191
  9.6. Discussion .......................................................................................202
  9.7. Conclusion .....................................................................................204

10. Analysis ............................................................................................206
  10.1. Construction of the laboratory ......................................................206
    10.1.1. Students’ willingness to adopt remote education ....................214
  10.2. Students’ perceptions of the laboratory .......................................215

7
10.3. Students’ belief in the realism of the laboratory ............................... 226
10.4. Improvements ................................................................................. 235
10.5. Engineers Australia education requirements ................................. 239
11. Conclusion ......................................................................................... 245

12. Appendix 1 ......................................................................................... 253

12.1. Accessing laboratory ...................................................................... 253
12.1.1. Instructions given to students ...................................................... 253
12.1.2. Invitation emailed to students regarding survey ....................... 255
12.1.3. Proposed Survey questions ......................................................... 259

12.2. Student responses to survey questions ........................................... 263
12.2.1. Student response to survey question 1 .................................... 263
12.2.2. Student response to survey question 4 .................................... 263
12.2.3. Student response to survey question 5 .................................... 264
12.2.4. Student response to survey question 13 .................................. 264
12.2.5. Student response to survey question 14 .................................. 265
12.2.6. Student response to survey question 15 .................................. 265
12.2.7. Student response to survey question 16 .................................. 266
12.2.8. Student response to survey question 17 .................................. 266
12.2.9. Student comparison survey question 4 and question 13 .......... 267
12.2.10. Student comparison survey question 14 and question 15 ........ 268
12.2.11. Student weighted output when observing learning focus ........ 269

12.3. Google Analytics data collected ..................................................... 270
12.3.1. Example time period ................................................................. 270
12.3.2. Raw data collected from Google analytics during this time period

270

13. Appendix 3 .................................................................272

13.1. Communication between devices .........................................................272
13.1.1. PYTHON Data receive from pi and store in database ......................272
13.1.2. PYTHON Data sent from pi to store in database ..............................276

13.2. Laboratory graphical data display .........................................................280
13.2.1. HTML Laboratory display live updates code .................................280
13.2.2. PHP script to collect live updating data from database .................286
13.2.3. HTML Laboratory display logged data code (2 hours) ...............288
13.2.4. PHP script to collect logged updating data from database (2 hours) 293

13.3. Google Analytics code .................................................................295
13.3.1. Student behaviour tracking .........................................................295

14. References ..................................................................................296
Table of figures

Figure 1: Devices students use to support online learning (Firipis, Joordens, 2015) .................................................................64
Figure 2: Inverter configuration during standard operation (Power One, 2009). 73
Figure 3: Shows the overview of the hardware chosen and its purpose in relation to student access.................................................................79
Figure 4: Shows the comparison of the web site accessed from a phone compared to a computer browser .................................................................83
Figure 5: View of FACET board during practical video .................................................114
Figure 6: View of oscilloscope during practical video .................................................115
Figure 7: View of software and calculator used for practical video........................115
Figure 8: Shows a brief overview of the remote laboratory structure ...........123
Figure 9: Raspberry Pi once configured .................................................................124
Figure 10: Shows the connection between the inverter and Deakin University logging data that the Raspberry Pi intercepted .............................................125
Figure 11: Shows the inverter used to gather solar data .............................................126
 Figure 12: Shows the communication overview of the Raspberry Pi ...........127
Figure 13: Flow of information through logging hardware........................................128
Figure 14: Overview of communication between logging hardware and web server .................................................................................129
Figure 15: Shows the output CSV file of solar data generated by the remote laboratory .............................................................................131
Figure 16: Shows the output graph of live data being generated, measured in joules .................................................132

Figure 17: Shows the output graph of two hours’ worth of data, measured in joules ..................................................................................................................133

Figure 18: Shows the output graph of two hours’ worth of data with fixed x axis, measured in Watts ......................................................................................................134

Figure 19: Shows the mobile device interface for this remote laboratory ..........135

Figure 20: Shows the zoomed in interface for mobile devices ......................136

Figure 21: Server handling of student queries .................................................137

Figure 22: Shows the overview of the hardware used by students to access online material (Firipis, Joordens, 2015) .............................................................................142

Figure 23: Operating system used by students accessing remote laboratory ....143

Figure 24: Browser used by students to access remote laboratory .................144

Figure 25: Student activity over time (12/07/2016 – 12/08/2016). .................144

Figure 26: New and Returning visitors of the remote laboratory ...................145

Figure 27: Initialisation code outputs ..........................................................158

Figure 28: Menu to access log files ..............................................................159

Figure 29: Outputted log file from 30/03/2014 ..............................................159

Figure 30: Response trends for question 2 of the survey ............................164

Figure 31: Response trends for question 7 of the survey .............................164

Figure 32: Response trends for question 8 of the survey .............................167

*Figure 33: Combined student responses to Question X on survey* ...............174

Figure 34: Example of data a student will see if looking at a 24 hour window ..186
Figure 35: Student engagement when they feel although they are acting on the laboratory hardware directly .................................................. 188

Figure 36: Diagram of student perception with very little presence being felt.. 188

Figure 37: Responses to the question “I felt like the data being generated was real” (Q13) ........................................................................................................................................................................ 192

Figure 38: Response to the question "I felt like I was completing a computer simulation" (Q4) ........................................................................................................................................................................ 192

Figure 39: Question 4 and Question 13 comparison ........................................ 193

Figure 40: Combined data from Q4 and Q13 ................................................ 194

Figure 41: Comparison to the responses from Q4 and Q13 .......................... 195

Figure 42: Responses to the question "I felt like the equipment being used to gather data was real" (Q14) ........................................................................................................................................................................ 196

Figure 43: Responses to the question "I felt like I was in an environment created by a computer" (Q15) ........................................................................................................................................................................ 196

Figure 44: Question 14 and Question 15 responses ................................... 197

Figure 45: Combined data from Q14 and Q15 .......................................... 198

Figure 46: Comparison of responses from Q14 and Q15 .......................... 198

Figure 47: Response to the question "I felt like I was completing a laboratory using real equipment" (Q5) ........................................................................................................................................................................ 199

Figure 48: Comparison of the responses to question 5 and question 14 ....... 200

Figure 49: Question 5 and Question 14 when combined ........................... 200

Figure 50: Comparison of Q5 and Q14 combined with Q15 ................. 201

Figure 51: Responses to the question "I felt like I was physically in the environment logging data" (Q16) ......................................................... 201
Table of Tables

Table 1: PVI-3.0 Inverter specifications (Power One, 2009) ............................74
Table 2: Release schedule and total length of practical videos .........................112
Table 3: Different media codecs supported by Google chrome and Mozilla Firefox (http://www.diffen.com/difference/Firefox_vs_Google_Chrome) ..................150
Table 4: Example of outputted log file starting at 9.00AM on 26/02/2016 .......157
Table 5: Sample of student responses from survey question 2 .........................163
Table 6: Sample of student responses from survey question 7 .........................166
Table 7: Sample of student responses from survey question 8 .........................168
Table 8: Students’ perception on lab focus of hardware being used ..............169
Table 9: Students’ perception on lab focus of theory of specific lab ..............170
Table 10: Students’ perception on lab focus of calibration principals ............170
Table 11: Students’ perception on lab focus of practical links to theory .........171
Table 12: Students’ perception on lab focus of signal analysis .......................171
Table 13: Students’ perception on lab focus of general engineering principals.172
Table 14: Students’ perception on lab focus of General feedback ..................172
Table 15: Weighting given to specific survey responses ...............................173
Table 16: Comparison of students’ perceived focus over multiple content delivery mediums (Lindsay, E., Liu, D., Lowe, D., Murray, S., 2007) .............180
Table 17: Weighting given to each survey response .......................................194
1. Introduction

One of the earliest cases of a remote laboratory being used in education involved controlling a robot arm for a control engineering course. The designers were constrained to using exceptionally slow internet speeds on what we would now consider primitive computers. The lab demonstration allowed users to press buttons on a children’s toy located in Corvallis, Oregon (Shor, Bohus et al. 2011). At the time many people believed it to be pre-recorded footage, and it was only with the random inputs they were allowed to use, and people walking in the background that proved otherwise. With increase in technical capabilities, research effort, remote laboratories and the pedagogical focus behind them, remote education has since evolved, becoming significantly more sophisticated. The benefits and advantages of remote laboratories is still a point of research, often being compared to computer simulations, as well as the more traditional laboratories that are held in person at a designated location.

Remote laboratories offer students a new way to be presented with the required learning materials for their undergraduate or postgraduate level studies, and are often utilised by engineering disciplines to act as either a replacement, or as a compliment of the practical sessions required in the engineering studies. Remote laboratories allow students to access the practical equipment from a remote location, often benefiting those not in direct contact with the university campus. This is their main difference from real world laboratories, in that real world laboratories require the students to be physically present. Simulations are often utilised by educational institutes due to their low cost, while still being able
to present the correct information to the students, often allowing for educational models to be isolated and analysed. The ability to show either extremely large or extremely small models in a simulated environment cannot be overlooked. Their main difference between simulations and remote laboratories is in the fact that they do not have any real world equipment that is being analysed, as everything is modelled by the software running the simulation. This is not inherently a negative, as having the ability to isolate specific models can be of great benefit, as well as the ability to pause and even rewind a specific concept can be of assistance when students are first being introduced to a new concept.

Remote laboratories offer benefits to universities in that the required equipment needed to set up and maintain a remote laboratory is measurably more efficient when observing the laboratories time of use (Lowe and Orou 2012). This is due to equipment in standard laboratories being used only during university hours and only while the laboratory is being supervised. In contrast to this, students using remote laboratories have access to the physical apparatus near 24 hours a day. Compared to real world laboratories, remote laboratories offer another advantage for time spent in use in that they can be used not only by the students at the controlling institution, but shared and evaluated by others in a method similar to the Da Vinci project (Müller and Ferreira 2005). With remote laboratories, due to students being able to access them at any time, they have also seen increased usage from students who can complete the laboratory experiment multiple times without the required setup and supervision normally associated with practical sessions, saving the university on time and money while also increasing the amount of study resources available to the students.
The use of remote laboratories in other universities also has the benefit of allowing remote laboratories to be utilised in proving engineering education to students (the Da Vinci project or Labshare) in universities that would not have the funds to purchase the required equipment. Allowing multiple institutions to share the same equipment by remote laboratories, the time the equipment is in use is dramatically increased compared to if only a single university institute were to utilise it. Remote laboratories are also advantageous in that for a university with minimal budget for the engineering discipline, purchasing equipment such as function generators for students for what could be as little as one week of practical sessions becomes a hard cost to justify, especially when equipment can be accessed from via remotely accessing the facilities of another university. Remote laboratories therefore allow the students to gain experience on this equipment while drastically lowering the costs to the university.

Remote laboratories are often separated into one of two categories, those being batch or interactive laboratories. Batch laboratories are controlled by a user inputting set parameters into the experiment and then leaving the experiment apparatus to automatically complete the experiment, logging back into the system once these parameters have been tested to view the result. Opposite this is the interactive setup, where the student views the experiment as it is happening, being able to control the parameters of the experiment in real time to change the input values of the system. Both laboratory configurations have their benefits and disadvantages, including the batch experiments ability to handle high demands of students while interactive setups often require the use a booking system, as well as the interactive experiment having a higher degree of presence for the user. It
is important for researchers to understand the uses of both when analysing the pedagogical differences.

An important concept to consider while analysing remote laboratories as teaching tools is the amount of presence a student feels when completing the lab. The feeling of ‘being there’ has shown to provide benefits to students as it has been shown to benefit students as it increases immersion (Bulu 2012). The participant completing a remote laboratory’s belief that the equipment they have control over is real, and their immersion in the lab due to this, is a very important pedagogical consideration that must be analysed when observing the effectiveness of a laboratory. Having a lab that makes the user feel detached from the physical equipment may make the user feel although they are completing a simulation, therefore their perception of the experiment may change.

The importance of students believing the equipment is real also links to students’ belief in the validity of the data being presented to them. It is understandable that if a student does not believe the equipment measuring information is real, then the data accuracy may also be questioned. Due to this, a method of establishing realism of equipment and realism of data must be established. Often this is handled by the user interface of the laboratory, ensuring that either students have a camera feed to the laboratory or that there is a clear, often in real time response to their inputted commands.

Presence is also important in the remote laboratories for students to believe that what they are doing is real, connected to the real world and an accurate representation of the theory they are being presented. Much like being physically
present, the ability to observe changes in a system after manually adjusting the inputs is important to students in their ability to retain information.

It has also been shown that as students are presented with identical information, but in a different format, be it through remote laboratories, simulations or traditional laboratories, the students’ perception of the learning outcome is also affected. By presenting the information to students using different media, it is possible to create a focus on a specific learning objective, such as practical links to theory or hands on experience, even though the information being presented is the same, with the only difference being the media in which the information was presented. It can also alter students’ perception of the laboratory focus. By being able to control what students approach the learning content, what they believe the laboratory focus and learning objective of the laboratory are, a practical laboratory can be a tool used to both teach engineering students the required content, but to also control how they approach learning that content, and how they see it as relevant to their overall engineering studies.

With this in mind, researching the differences in students’ perception could be key in better understanding the best method of presenting students with the learning material. By manipulating the media in which students are presented information, or even the degree of realism of the information being presented to the students, it may be possible to have further control over their learning environment, and provide an increased understanding of how students learn in a remote education environment.
1.1. Aim, Objectives and Research Question

This research aims to answer the question of how will the inclusion of real time and real world, functioning system outputs into an engineering remotely accessible laboratory change the way that students perceive the importance and relevance of the information with respect to their overall engineering education, with this information including their perceived laboratory focus and the interpreted learning objectives compared to the current remote laboratories. This research aims to increase the level of realism in the information presented to students, giving them access to a working system instead of a model of a system. In this way, students will be able to access a remote laboratory that allows for the access of outputs in a currently implemented and functional engineering system. Analysis will therefore be conducted on a novel, purpose build laboratory that has yet to undergo this level of scrutiny.

This research also aims to answer the determine the extent of information presented to students to establish and maintain a belief of reality, having students believe in both the validity of data being presented to them, as well as the realism of the equipment being used to generate this data. The links between this analysis and the feeling of presence will also be analysed.

Finally, the question of what devices students will use to access this laboratory and at what frequency will be answered. This is useful for analysing and software requirements for the laboratory. The students’ access behaviour will also be analysed.
Research into the method in which students learn in remote laboratories has focused on the difference between remote laboratories, traditional laboratories and simulations. This research has shown that the degree of realism in a practical session, simulated, remotely accessed and in person, has been shown to affect not only what students learn in a practical session, but also what they believe the emphasis on the learning exercise or laboratory focus is. If it were possible to replace realistic simulated inputs, or remotely accessible models with real world inputs taken from a functional system instead of a model, it could be possible to affect the way students perceive their learning experience.

Due to this, it may be possible to place an emphasis on different learning outcomes, such as practical links to theory or solidification of theoretical rules, by changing the format in which students are presented information within a specific medium. Highlighted by this is the fact that if different methods of presenting information to students is analysed, it may be possible to better tailor a learning environment for the students, via not only ensuring that students receive and retain information, but also that the way in which they perceive that information to be applicable to their studies can also be determined and controlled.

Current research is investigating the effects of realism on remote laboratories, however using real world inputs from outside the laboratory instead of realistic simulations or a physical model has yet to be done in remotely accessible labs in the method described in this text. Having real equipment responding to inputs in the real world, not models or simulations, could be the next step for this technology.
In addition to this, students currently are often given access to a live camera feed of the remote laboratory being completed. This is done with the intention of increasing their belief in the realism of the equipment being used to generate the results that will be displayed to them. With a laboratory utilising results from a real world system, the effect of students’ belief in the validity of the data must be analysed, as methods of increasing presence may not be required, or may require further development.

1.1.1. Aim

The Aim of this research is to develop an educational research platform in which to remotely present students information in the form of a practical experiment. This platform will present to students the outputs of a renewable energy system as it is used to create solar power in real time. Students will therefore have direct access to a functional renewable energy system generating power through solar panels with solar inputs. In order to increase their exposure to this system, the logged files for up to three years’ worth of solar data will also be made available to them. With this remote laboratory, it is aimed to analyse the methods in which students learn, given the outputs of this system will be subjected to the noise created by real world inputs. This aims to identify the students’ perceived learning objectives and learning outcomes. This will be used in order to establish a new method of presenting information to students, and to determine the emphasis students place on this new method of presented information. Additionally, a study into the accreditation of engineering will be undertaken with emphasis on remote education in undergraduate engineering programs.
Due to the fact that students will be presented with this information, a study of their belief in the validity of the data being presented to them will also occur. This study will cover their belief in the realism of the equipment being used to generate the solar data, the actual data being presented to the students, such that they believe it was not the result of a computer simulation, as well as the degree of presence felt while completing the laboratory. These factors will be heavily influenced by the fact that the remote laboratory will not utilise a camera feed to present students with video feedback of the system. Instead they will only be presented with the solar energy being generated at the given time, allowing them to see the effects of changing weather conditions on the solar outputs, as well as the change in solar power generated at differing hours of the day and even over an extended period of a few years.

Finally, an analysis of the methods students use to access this laboratory will be undertaken. The number of new and returning visitors will be analysed, the access device and operating system used, as well as the web browser chosen will be analysed. This information will be critical for developing laboratories in the future, as there are benefits of each access mode, so knowing which one is favoured by students means the laboratory functionality could be updated to better reflect these benefits.

1.1.2. Objectives

The objectives of this study will be presented numerically below. They highlight both the qualitative and quantitative nature of this research, as both
numerical data will be collected, but research will also include student feedback, therefore requiring analysis of qualitative data.

1. Develop a remotely accessible laboratory using real world inputs.
2. Qualitative analysis of the students’ experience completing the remote laboratory.
3. Quantitative analysis of data generated from the remote laboratory, including metrics such as access time for the laboratory and access device.
4. Analysis of the differences in perceived learning outcome of the students in this remote laboratory format.
5. Develop conclusion on the differences in learning experiences for students when presented with real world inputs in a learning environment.
6. Analyse students’ perception of realism in data, including belief of realism in data, and of the equipment

1.1.3. Conclusion

This document will begin with a literature review into current methods of student learning in distance education. It will focus on the Clark-Kozma debate (Clark, 1983, 1994 Kozma 1994, 2000), and its relevance to remote laboratories as well as simulations as different media that could be used in order to assist the educational process. It will also cover presence in remote laboratories, observing the currently established educational benefits and differences between remote laboratories, traditional practical classes and simulations. After this, there will be a review on students’ interaction with different remote learning mediums. It will then focus on presence and ways to measure student learning. An outline of the
proposed methodology of this research will be provided, as well as information pertaining to the specific laboratory that will be set up, including the parameters of influence and outputs of the experiment.

After the literature review, there will be a section covering the design goals of the remote laboratory. This section will cover some of the required functionality of the laboratory, as well as methods used to gain extra functionality. It will primarily focus on students accessing the laboratory, and attempting to make this as simple and intuitive as possible. After this section, the method used in this research will be discussed, covering topics such as selecting research participants, as well as the structure of surveys used to collect data.

A review of students accessing the laboratory will then be done, in order to establish the willingness of students in current engineering education to adopt remote education as an educational medium. This will be done in order to establish the learning patterns of the students that are studying engineering primarily attending on campus.

After this, all results of research will be presented, followed by a discussion of these results and their implications. The results will be separated into three sections, with the first of these three focusing on how students accessed the laboratory, the devices they used to access the laboratory and access behaviour. The second section will analyse students’ perception of the learning objective and laboratory focus of the laboratory, and the third will analyse students’ perception of reality in the laboratory, allowing for the analysis of the students’ belief in realism of equipment, belief in validity of the data and the presence felt by
students completing the laboratory. After the analysis, a final conclusion will be presented.
2. Literature Review

With the introduction of new teaching methods, including remote laboratories and computer simulation, the pedagogy of different media in teaching must again be analysed. Now that research has been completed in the field of educational mediums focusing on areas such as student perception of the material and the availability of such resources, as well as the learning benefit of each medium, the question of the best media to use in each environment must be studied. Due to this, perhaps is it time that the Clark-Kozma debate to be revisited. Now that student perception of a learning outcome can be a metric for discussion, as well as at the time unavailable technologies such as the internet providing education in a way that was simply not possible at the time the debate began (with Kozma even stating that without properly utilizing computers, they would regress to the point where they would be utilized to purchase real goods with real money).

In addition to this, since the debate, entirely new methods of providing education to students has been established, that being remote education and remote laboratories, which offer an alternative to computer simulations, which were used at the time of the discussion, and these new methods of education must be analysed for their possible pedagogical advantages (Stefanovic 2013). In addition to newer media in which to provide education, new methods of study have also become more popular, such as off-campus modes or remote modes of study and the relatively newer MOOCs (Massively Online Open Course) (McAuley, Stewart et al. 2010, Breslow, Pritchard et al. 2013). The increased popularity of remote education creates a need to analyse the method of providing education
to these students, as using the standard classroom teaching methods is no longer an option for every student (Potter 2013), and therefore remote education methods must be analysed, not only focusing on the advantages and disadvantages of both mediums (Corter, Esche et al. 2011, HAMPEL 2014), but also the students’ ability to interact with both mediums, and their engagement of each (Lowe, Machet et al. 2012). Quality assurance for online education must be ensured (Britto, Ford et al. 2013).

Computer simulations, providing both interactive models and functional models are currently being used to aid in the remote education process, in undergraduate education as well as primary and secondary education (D'Angelo, Rutstein et al. 2013). With computers becoming more advanced, the level of detail, interactivity and realism can only increase. However, these simulations are just that, simulations. With no real element to them they offer unique advantages and disadvantages (Garcia 1994). Once the simulation is downloaded or installed onto a computer, there is no need for a physical apparatus. In addition to this, a simulation allows for the model to be paused, rotated and to show incredibly small or large objects in great detail (Wu, Lee et al. 2013, Miller, Singh et al. 2014). Due to these advantages, running simulations can provide the much needed education to remote students and MOOC’s, without the need for a physical presence to provide this education. Knowing the strengths of an educational medium therefore is becoming a very important tool in one's arsenal to determine the specific educational medium to utilise in different teaching formats. In this vein, simulations are also used as they also offer advantages in training in that they can
be completed online with either immediate feedback or feedback provided after the training (Wayne, Didwania et al. 2008).

A relatively newer medium to appear in education has been remote laboratories. Utilising the internet, remote laboratories give students access and control of physical equipment from their computer or laptop. This is done via webcams providing students with feedback of the experiment and all experiments being controlled using tele-operational methods. Remote laboratories, originally designed to provide remote students the ability to complete practical experiments without the need to attend in person, share similarities with simulations, but also key differences (Balamuralithara and Woods 2009). The ability to control a physical apparatus forces students to perceive the learning outcomes differently, and due to this can be manipulated into focusing on different learning styles (Corter, Nickerson et al. 2004). In addition to this, by being able to log into a system and complete a practical experiment at any time and from any location, remote laboratories offer a new method for delivering education to students. The degree of realism in remote laboratories has briefly been researched, however has still been based off of models of real world scenarios. Remote laboratories can also reduce costs in physical equipment, as often less equipment needs to be purchased (Hassan, Domínguez et al. 2007).

This review will analyse the Clark-Kozma debate (Clark, 1983, 1994 Kozma 1994, 2000), focusing on the differences of the two opinions in relation to the media available at the time, and then analyse the differences in the emerging media of today, showing the relevancies of this debate, as well as provide insight
into the areas that could not have been discussed at the time of the Clark-Kozma debate. It will focus mainly on remote education, and the associated media required for the two of them, with an emphasis placed on remote laboratories and simulations. The review will introduce concepts that can affect students’ ability to learn in a remote environment, both directly and indirectly, and also cover the literature that focuses on students’ perception of learning objectives in different remote education media.

2.1. Clark Kozma debate

The idea of using different media in education sparked a debate as to the advantages, if any, of utilizing specific, and differing media for different applications. While not the only two people to give their opinion in the debate, Clark and Kozma definitely framed the discussion. Clark initially presented the opinion that the differences in media do not have an effect on learning outcomes (Clark 1983). He gives his opinion in the two delivery trucks metaphor, stating that it doesn’t matter which truck makes the deliveries, as the contents of the truck remain the same. He states that the only difference is the cost and speed of delivery, linking this with different media uses in education. This also links to the idea that for media to be relevant, it must have a factor, or symbolic element that is irreplaceable. This idea links to remote labs and simulations in that both are often seen as filling similar niches, and therefore other advantages must be analysed. However, as will be discussed below, remote laboratories and simulations are not interchangeable, as the students experience on each can differ. Being able to accurately know what students experience on a learning
medium, and how to adequately teach them within the requirements of a course is important knowledge, leading to the Clark-Kozma debate, and the discussion around it.

In order to demonstrate his belief that media does not influence education, Clark cites a study (Kulik, Bangert et al. 1983) that found the use of computers as a medium to teach students did at times show a statistically significant increase in learning when compared to the standard method of teaching, showing that a computer based medium can increase learning by “approximately .32 standard deviations” (Kulik, Bangert et al. 1983). The point of referencing this paper however, was that it also found that the period of time on these studies becomes important, and that “effects were also greater in studies of shorter duration” (Kulik, Bangert et al. 1983). Clark claims that it was shown by Kulik, Bangert and Williams that with the difference in examination results decreasing from 0.56 standard deviations over studies lasting four weeks to 0.2 standard deviations for studies that last longer than eight weeks. This effect is also shown in a study analysing the effects of students being tutored, which found that “tutoring effects were larger in ... tutoring programs of shorter duration” (Cohen, Kulik et al. 1982). Clark presented the view that differences in learning when using novel media (in this case computers as a teaching aid compared to standard teaching methods) and due to “the novelty effect, these gains tend to diminish as students become more familiar with the new medium” (Clark 1983). This is also reflected in visual media, where it was found that “74% of the studies of student achievement re-reported no significant difference between visual-based and conventional teaching” (Cohen, Ebeling et al. 1981). From this paper, Clark
claimed that while the statistical significance of difference in results over extended periods of exposure reduced over time, the studies included methods containing multiple different visual media (television, images etc.) making results “hard to interpret” (Clark 1983).

Another of Clark’s initial arguments, one that he uses in many of his discussions, is that the media used is not responsible for the outcome of the experiment, but instead the method used influences the results. It was found (Kulik, Kulik et al. 1979) that variables such as the instructor need to be controlled, as their studies on the differences between Kellers Personalised system of instruction (PSI) and traditional teaching methods found that “final exam scores were 73.7 and 64.4 for PSI and conventional sections, respectively, as opposed to 72.9 and 66.6 when a single instructor gave both classes” (Kulik, Kulik et al. 1979). While they did find a statistically significant increase in using PSI over traditional teaching, raising the score of a typical student from the 50th to the 70th percentile, this difference was larger while using methods involving different instructors. In this way he argues that any differences in media are instead related to the quality of instruction that the students are receiving, and not due to any differences in the media itself.

In response to Clark, Kozma (Clark 1994) proposed that the media selected does influence learning, stating that the debate needed to be rephrased to better accommodate the ways education have evolved. When showing that different media can effect learning outcomes, he cites White (White 1993).
White used computers as a medium to teach grade five and six students the basics of year eleven physics, covering topics such basic Newtonian mechanics. The results gathered show not only the benefits of using computer simulations (using Thinker Tools) compared to standard teaching methods, but also analyse students who have never studied physics, so can also gauge the increase in learning from standard methods of teaching. White found that the 5th and 6th graders with exposure to thinker tools performed significantly better on the tests than those year eleven students studying under traditional methods, citing that the use of computers to aid education allowed the students to better grasp concepts.

The method used in this study is often criticized (Morrison 1994), with claims that the same results could be possible if “the instructor had taken the control sixth-grade class to a billiard parlour and allowed them to conduct similar experiments” (Morrison 1994), and that the study shows “manipulation of objects vs. traditional instruction” (Morrison 1994). Morris uses this example to claim that the method used for the study is not comparing the differences in media, but instead the differences in the tools easily available to each media. This raises the idea that perhaps the question should not be ‘Does different media enhance learning’ but instead ‘which media will be the best to implement’ or even ‘how does media affect learning?’ A potential problem with this analysis is the question of the differences between media and their respective methods of educating.

A similar complaint by Morris is made about other papers cited by Kozma to support his viewpoint (Kozma 1994). This study (Van Haneghan, Barron et al.
1992) aimed to analyse the differences in response from students to a complex worded problem using either a visual medium (television) to show the problem to students, or instead using text. He claims that as the visual medium produced better results, showing that a visual medium has the capability to enhance the students’ ability to express complicated models, and therefore that the visual medium is better suited to this application. This shows that although the same information can be presented to students, their interpretation of that information can be different depending on the method in which that information is presented, perhaps leading to the thought that if you present students with information in a different format to what is currently available, they too might learn differently on it.

This study also has queries raised by both Morrison (Morrison 1994) and Clark (Clark 1994) in that an argument can be made that more information is given to the students in the visual medium. Due to this, Clark claims that “the study failed to control for instructional method and is therefore confounded” (Clark 1994). In contrast to this, Kozma claimed that method and medium should not be separated and should instead be considered one and the same. This study emphasizes this opinion, in that only by using a simulation could a standard classroom have this technology. This raises an important point when observing the differences in media (Kozma 1994). If the media used does not appear to offer any advantages or disadvantages, is the method of each media something that should be considered. The aspect of each medium that greatly offers effective learning methods should be further studied (Bell and Federman 2013), and
therefore shouldn’t media that has a method that teaches students more effectively be selected over one that doesn’t?

This argument highlights an important difference between the two parties, that being that if the differences in result is due to the media passively offering different information, can the two truly be compared? Kozma would say yes, as the two studies demonstrate. He offers the opinion that media should be analysed with the inherent attributes and differences to that media included in the analysis, not discounting the inherent differences in media while observing results of the study. The claim is made that research into pedagogical advantages of any medium must include more than just students’ final grades (Kozma 2000).

A problem with the Clark-Kozma debate is that the assumption is made that all media will be available, and therefore the criteria for each is based solely on cost/delivery time/education outcomes. While this may have been true of the examples they cited, with the addition of the internet and newer technologies aiding in education, students are expecting much more flexible study options. It is now possible with remote education required for many different media is subjects such as sciences and engineering to provide education to students who cannot attend a standard classroom to receive education. With E-learning becoming more common, and cloud linked students now a reality, the differences on both student and staff are being analysed. Requiring students to travel to the university to complete practical sessions not only becomes unpractical for some students, and can be difficult to give the same level of time as for off campus students. Due to
this, the creation of simulations and remote laboratories were made out of necessity.

2.2. Remote education

Just as Clark and Kozma both analysed the benefits of using different media in education, researchers too have analysed the uses of remote education. Although the Clark-Kozma debate did not focus on the differences between possible remote educations benefits, research has been completed in order to determine any advantages to using the different media available in newer media, including those used in remote education (Feisel and Rosa 2005), and laboratories for undergraduate education (Rivera, Larrondo-Petrie 2016).

A study (Balakrishnan and Woods 2013) analysing the learning techniques of students in engineering and their perception of both simulations and physical laboratories found that students preferred physical laboratories, but attributes this to the time it takes for students to become accustomed to the simulated environment.

The study also mentioned that most of the students in engineering are “kinaesthetic learners, which could contribute to the reason why the majority of the respondents prefer hands-on lab exercises” (Balakrishnan and Woods 2013). While the students stated that they preferred hands on laboratories, when interviewed, it was stated that “a large number of participants in the interview commented that the output of the simulation lab experiment was good, as predicted; on the other hand, the students said that the output of the physical lab exercise was poor.” This difference is believed to be the result of physical
laboratories having the possibility of faulty equipment. The difference is important however, as the output of an experiment aids students in further understanding of conceptual knowledge, and therefore the controlled output of a simulation can be beneficial.

The study found that students preferred physical labs but interestingly the students scored higher on reports written from a simulated lab and not a physical lab. Balakrishnan and Woods conclude that while physical labs are beneficial in some instances, there are others that a simulated lab could be beneficial, and even recommended. While this conclusion is in opposition to Clark’s beliefs, who claimed that the longer a student is exposed to a medium, the less likely a learning difference to occur, he was not mentioning this argument in reference to computer simulations. Comparing remote laboratories to simulations, students showed a preference for remote laboratories, citing a preference for being able to witness the experiment being completed, and having more trust in the authenticity of the results (Jona, Roque et al. 2011). Students have also shown preference for remote laboratories due to having more times that the laboratory is available (Gadzhanov, Stamen et al. 2017).

Remote education as an education medium has received scrutiny to ensure it is as beneficial as being physically present for education. Simulations are often used in parallel with standard teaching methods (i.e. Being physically present), but as education tools in isolation are being studied for their pedagogical advantages. Similarly, remote labs have been designed not with the intention of replacing practical experiments, but to act in parallel with current educational methods, but
also to be utilised when another method of education becomes unfeasible. An issue with remote education is that the attrition rate can be up to 10-20% higher than on campus units (Angelino, Williams et al. 2007), and therefore methods of further engaging students in remote education should be continued along with the current studies that involve analysis of student feedback (Lindsay, Liu et al. 2007).

This is especially true with newer methods of educating students, mainly off campus students and massively online open course (MOOC) students (Mackness, Mak et al. 2010). MOOC students especially, as this style of education is aimed at providing education to students from across the globe, and therefore to students whom cannot be expected to be physically present to complete practicals. The requirement of remote education becomes important for these two categories of students, as being physically present is often not possible, however to complete the requirements for an engineering unit often requires completion of a practical component. However, knowing the best method to teach on these mediums is increasingly important, as education becomes more available students will need a medium to learn on that will be able to cater to their required learning outcomes.

Remote education, including remote laboratories and simulated experiments, possess the ability to educate in ways that are not possible when using the standard laboratories (Cooper and Ferreira 2009). Due to the requirement of most simulations and remote laboratories to be completed by a student even without an instructor present, a student must be able to interact with the medium in
entirely different ways. It is also possible to allow students to learn on equipment in entirely new ways, including hybrid labs that involve elements of each laboratory (Abdulwahed and Nagy 2013).

The first method students interact with the newer media differently to standard physical experiments that will be discussed in this review is self-directed learning (Böhne, Faltin et al. 2002, May, Terkowsky et al. 2013). While not a new concept, it is a requirement for distance education. Allowing the student to use self-directed learning offers advantages over other media in that they allow for information to be presented in the media, instead of before learning. The requirements are placed on the student to actively engage in learning the material without an instructor present.

As mentioned before, computer simulations have not always been shown to offer a direct advantage of learning outcomes compared to traditional media (with some exceptions (Finkelstein, Adams et al. 2005)). However, the method they use to teach can be drastically different, and should therefore not be discounted. Different learning aids for computers are available, such as visual aids as well as audio aids and interactive texts such as hyperlinks (Aldrich 2005). Remote education and simulations, with the ability to have movement of models, or detail that is not possible to show in a book, as well as abilities such as zoom and animated pictures assist in an individual’s ability to create a ‘mental model’, a step that is crucial in understanding things such as Newtonian mechanics (Andaloro, Donzelli et al. 1991), and can be done through remote mediums instead of through the traditional method of using a textbook.
Another key difference in remote educated practicals are that they allow students to utilise hypothesis testing before the experiment. This is the requirement for a students to input a hypothesis to the outcome of an experiment before continuing to subsequent stages of any given experiment (Moore, Chamberlain et al. 2014). While this is not exclusive to remote education and simulations, studies in this area (Chang, Chen et al. 2008) have been soon to focus on this attribute of simulations. It was found that when students were asked to select a hypothesis, in a predict-observe-explain format, students were able to better solve target problems (Monaghan and Clement 1999). This affect also worked when students were given multiple hypothesis to choose from, however this study also showed that the affect only occurred if the students were perceived to view the concepts to be covered as being easy, as more convoluted hypothesis, where the solution was either counterintuitive or unfamiliar to the students, the effect was noticeably smaller.

It should be noted that while this method could be completed in a physical laboratory, simulations and remote experiments must be built around a user interface that the student interacts with, and it is often by utilising this user interface to force students to participate in hypothesis testing that creates the difference.

Computer aided learning and simulations are often viewed as being different to other media due to their ability to interact with the student, making the student an active agent. This allows for a unique interaction with the learning medium not available in the standard teaching environment. By forcing the student to ether
input correct results before continuing on in the experiment, or to have viewed a very specific outcome, a student is forced to show knowledge in the area being studied before continuing, and at the same time an active engagement can be used to tailor the learning environment to the students’ current skill level and understanding, evolving the learning process into one more helpful to the student (Wang 1997). This is different to physical laboratories and in fact standard education in that a student reading a book is not forced to prove understanding of one paragraph before being able to even see subsequent writings, and that the book will not update as the student gains more knowledge, or struggles to understand a concept. The capabilities to also track a student’s knowledge of a topic is also available, leading to scenarios where a student struggling can automatically gain assistance from a student who has shown competency in a topic, as well as competency in assisting other students (Anderson 2003).

By forcing students to show competency in a given area before being allowed to continue with the experiment, the education goals can be more easily monitored, and students’ understanding of very specific areas can be assured. It has also been shown (Graven and Samuelsen 2013) that when a student fail to show competency in a specific topic, the lab is capable of either prompting the student with more learning material, or forcing the student to stop the experiment in order to further prepare this knowledge. This technique has been used in electrical engineering laboratories, where if a student incorrectly assembles a circuit, the remote laboratory will log them out for a predetermined amount of time, informing the student of the error and giving them enough time to prepare a different solution. It is possible therefore to remove trial and error...
behaviour from an experiment by giving a time delay to students who attempt this method.

2.2.1. Computer Simulations

The use of computer simulations to aid education is by no means a new concept, they are beginning to see inclusion to teach many disciplines including engineering as well as the sciences (Khan 2011). Simulations offer unique advantages such as the ability to show graphs in real time as the simulation is running, as well as giving students control over which variables are shown and also allow users to pause, zoom in and control the graphical user interface in ways that cannot be done with traditional teaching mediums (Blake and Scanlon 2007). When observing the structure of computer simulations, it can be seen that each simulation will belong to one of two models, those being conceptual and operational. The conceptual model is often used to teach principals and concepts of a system (Trindade, Fiolhais et al. 1999, Kokalj 2003) and can be used in subjects such as chemistry to demonstrate models of objects much too small or too large to observe without specialized equipment. Opposite to this model is the operational model, which is used to show the procedure or task of specific systems (Hodge, Hinton et al. 2001, Vournas, Potamianakis et al. 2004, Goh, Wee et al. 2013). The operational model is often used to show engineering principal such as electricity flowing through a circuit or Newtonian mechanics. In addition to the differences in simulation types, there are inherent advantages to using simulations, and indeed computing as a medium, than a traditional classroom format (Graesser, Franceschetti et al. 2013). Things such as the ability to update information as the student completes the simulation, and to allow collaboration
with other students as required, often included in the simulation can assist in the learning process and can assist increasing student motivation levels (Spinello and Fischbach 2004).

Studies into computer simulations often are completed in one of two ways, either via using a simulation in order to compliment traditional teaching methods, or via using a computer simulation as a replacement for traditional teaching. When directly comparing the two methods of study, advantages to simulation over traditional media to educate are often witnessed (Wayne, Didwania et al. 2008), while similar studies have been shown outcomes that cite increased student motivation and exam attendance (López-Pérez, Pérez-López et al. 2011). An example of a study that used solely computer simulation compared to traditional media was completed (Trey and Khan 2008), attempting to demonstrated the use of computer simulations in a classroom compared to using models and text presented in a book, and how as a medium, computer simulations allow for the conceptual modelling stages of learning to be significantly accelerated. This advantage of using different media, in this case computer simulations, has also been shown by Kozma in response to Clark (Kozma 2003). It has also been shown that substituting computer simulations instead of traditional course work has much larger information retention (Jimoyiannis and Komis 2001).

Trying to increase the degree of realism students’ feel in simulations has been shown to have benefits for the students undertaking the simulation experiment. A study analysing the effect of realism in simulations used higher quality models to show students a nursing scenario, compared to lower quality
models (Nunez and Blake 2003). All other variables in this experiment were controlled to be the same. It was found in this study that when increasing the degree of realism, the students felt a larger presence in the laboratory. This is an important study in that it shows the more realistic something is perceived to be increases the degree of presence of students, even if the students are exploring the same virtual environments.

Nunez and Blake researched the effects of model fidelity in the perceived presence they felt in the simulation. Their research focused on simulations instead of remote laboratories. It has been shown (Sauter, Uttal et al. 2013) that students in remote laboratories approach learning differently than in simulations. In addition to this, the research completed by Nunez and Blake focused only on presence, not perceived learning objectives in different learning modes. The intention of mentioning the above study was to point out that the degree of realism already affects students in on-line environments and to link it to the findings that show that presence affects on-line learning.

Contrary to Clark’s belief (Clark and Feldon 2005), this study shows that different ways of presenting the same information have a definite effect on the methods in which students learn. It should also be noted that the uncanny valley, that being the point in which our degree of comfort with an object compared to its realism massively dips at it approaches realism has an effect on the degree of realism perceived by students to be maintained in the laboratory.
2.2.2. Remote laboratories

One of the first remote laboratories to be mentioned began its development in 1994-1995. The lab worked on dial up internet, and to today’s standards would seem quite simple. It involved controlling a robot arm in a control engineering course. Remote laboratories are often seen the engineering discipline, however remote laboratories are not restricted solely to engineering and there are examples of remote laboratories outside of this discipline. An example of this is in the sciences and other STEM courses (Alkhaldi, Tareq et al. 2016), where laboratories are currently being reviewed for their suitability in this discipline (Tho, Siew Wei, et al, 2016).

Current engineering remote laboratories are used to show students a wide range of concepts for practical experimentation such as the bending bar experiment, which shows students in real time examples of compression and tension (Lowe, Machet et al. 2012), projectile motion of a small ball bearing (Alves, Marques et al. 2013), renewable energy generation methods (Cotfas, Cotfas et al. 2013) and HVAC (Rampazzo, Mirco et al. 2017) or other control system (Yabanova, Ismail, et al. 2016). Interestingly, the HVAC system was used to create an industry partnership. Studies in remote laboratory use for ohms law (Garcia-Zubia, Javier, et al. 2017) found that the laboratory “produced a positive effect in students learning”. This was also supported by Chevalier, Amélie, et al (2016), who introduced a control laboratory over a three year period, and concluded that this positively affected students’ examination results.
The setup of most laboratories can be separated into one of two designs, those being batch and active laboratories, although other designs that combine the two approaches exist (Maiti, Kist et al, 2016). Batch laboratories involve the user setting parameters for the remote laboratory to test, and then allowing the laboratory to autonomously test these settings while the user is not actively engaged in the laboratory. The batch style remote laboratory will then be able to inform the user once all measurements have been taken, and all testing completed, allowing the student to log in to view all results. This has the advantage of allowing the equipment to constantly be testing without active students, increasing the uptime of the equipment, and being able to test at times students would not reasonably be able to attend the laboratory, such as when students would be sleeping. The output of these labs can also be presented in different ways. Due to having no time constraints in outputting information, a batch laboratory is able to show significantly more information as time continues, while active labs tend to rely on graphical outputs as a method to efficiently show the output parameters.

In contrast to batch laboratories are active laboratories. Active laboratories allow a student to have direct control over set parameters of the laboratory in real time. This setup allows students in real time to see the results and output of the laboratory. With a webcam to give students access to visual outputs of the laboratory, this increases the amount of presence that the students feel for the experiment.
The nature of remote laboratories means that only an individual students or team of students can be using the equipment at any given time. This has created an issue for individual students or groups of students all trying to access the same equipment across multiple groups. This was partially solved in the Sahara Lab architecture (Lowe, Machet et al. 2012) by the creation of a queuing system for the online remote laboratories (Lowe and Orou 2012). This queue ensured that not only were students made use the remote labs for only the time limit, but that if a student required, they could book the remote lab apparatus for a time in the future, and be able to ensure it was available.

This scheduling system allowed for laboratories to be accessed fairly by all students, but it also allowed the students to use the lab as a study resource after the experiment was completed. This point also opens up the fact that with remote laboratories, the students’ ability to use the laboratory equipment has evolved. It allows for students to witness models of real world scenarios occurring from home, showing outputs that would differ from simulations as they are being measured by real equipment.

While Sahara and LabVIEW exist as a way to assist people in creating laboratories, there are other options such as using a CubieBoard 2 (Lopes, Maisa, et al 2016), or an Arduino (Mostefaoui, Hakima et al. 2017) to create in house solutions (Wang, Ning, et al. 2016). This allows for an extremely large amount of flexibility in establishing exactly how to present the information to students (Williams, Wesley et al 2016).
This flexibility extends to access devices. Laboratories are accessible through the internet, meaning laptops can access them, but also mobile phones (Wang, Ning, et al 2017). The devices students use for remote education should be analysed to ensure student devices are capable of accessing the laboratory.

Another benefit of remote laboratories was shown with the Da Vinci Project, and the Lab Share initiative, in which available laboratories were compiled into a list available for all university unit co-ordinators to observe. This allows for the sharing of remote laboratory access between multiple institutions (Orduna, Garcia-Zubia et al. 2012, Orduña, Rodriguez-Gil et al. 2012). In the case of the Da Vinci Project, a pool of available laboratories was created, and therefore able to be shared amongst multiple universities. By utilizing remote laboratories, the students’ provided educational value does not have to suffer. This is true even if the host institute cannot provide access to physical laboratories, as students will be able to witness the concepts to be studied via remotely accessing a different universities equipment (Nafalski, Nedić et al. 2010). This also had the benefit of being in a different time zone to the students at the host university, so scheduling was not an issue. Methods of comparing remote laboratories to ensure consistency are currently being developed (Germán-Salló, Zoltán et al. 2017), focusing on areas such as effectiveness, efficiency, satisfaction, freedom from risk and context coverage. This also provides a possible solution to institutes who do not currently have access to hardware required to run specific laboratories, or need to rely on remote education for their practical experiments (Schlichting, Luis CM, et al. 2016).
Students in a remote laboratory must be more active learners in that they do not have an expert present to explain any difficulties. This results in students being forced to either seek answers from the provided information, or to seek help from other material not provided by the laboratory. Without a supervisor the onus is on the student to be able to solve all problems of the laboratory, as there is not an expert in the topic readily available. This forces students to be invested in the learning material, as some laboratories require them to prove knowledge before allowing them to continue.

The lack of supervisor in a remote laboratory also affects the construction of the laboratory. They differ from real world and simulations in that they must be able to completely reset after each experiment, often in a completely autonomous manner.

Because of this, a clear end state for the laboratory must exist, and a reset procedure introduced. This changes the role of the lab instructor in remote laboratory into one that not only focuses on ensuring the lab is capable of resetting, and fixing any issues with the equipment to ensure it is able to reset effectively. An example of why this becomes important is shown by (Alves, Marques et al. 2013) where the projectile motion of a ball bearing was being measured by students as it was launched out of the apparatus into an area designed to catch the ball bearing. The experiment had a one percent fail rate in catching the ball. This may appear small, however when the experiment was completed multiple times, by multiple students, this could occur frequently, and forced the laboratory to be offline until it was fixed. This shows the near zero
tolerance for mistakes that remote laboratory instructors must ensure their lab equipment must maintain.

Interestingly, with the introduction of remote laboratories, the pedagogical advantages of implementing simulations has become much more important. Both offer the advantage of being able to educate students in an off-campus and MOOC modes, and both allow students to learn in their own time via the internet, having the student act as an active agent.

When focusing on students’ belief of objectives, or rather what the students believe the learning objectives are, an important distinction between remote laboratories and simulations can be observed. The students’ perception of what the lab is supposed to be teaching is an invaluable tool to be aware of, as it can allow an educator to manipulate the students into learning very specific objectives. When asked to state what the learning objective of a remote laboratory is, it was found that 20% of students thought that the remote laboratory was about understanding the hardware, while only 6% of people undertaking the same practical but instead using a simulation believed this. Similarly, 25% of students completing a simulation believed the learning objective to be linking practical elements to theory, while only 4% of students completing a remote laboratory believed the same (Lindsay and Good 2005).

It has been shown that when students perceive an experiment as being real, they will interact differently to the experiment (Sauter, Uttal et al. 2013). This perception of realism is easier to create with remote laboratories compared to a simulation. While students in a remote laboratory environment believe the
learning outcome to be focused on interaction with the mechanics of the laboratory, such as Newtonian mechanics, and gaining hands on experience, a simulation is more likely to encourage students to believe that the desired learning objective of the simulation is to increase the users understanding of the principals behind the laboratory. This interaction is important, as with proper understanding, the students’ focus can be manipulated into focusing their attention on a desired learning objective. It also poses the question as to what degree of realism students require in an experiment, and if it is possible to create even more realistic laboratories, will this further affect their learning experiences, and to what degree?

2.3. Presence

Presence is an important part of remote education, as the feeling of realism with regard to their practical experiments is an important factor to students’ interaction with the education medium (Bulu 2012). Presence is often separated into multiple categories to make analysis simpler. These categories are physical presence, tele-presence and virtual presence. Control of these three factors can alter students’ perception of reality, leading to more control over the learning behaviours of the students’.

When observing remote laboratories and computer simulations, presence refers to the perception of reality, however has been further defined by multiple people in different ways. The feeling of being involved, or ‘being there’ can affect students’ actions in a virtual environment (McCreery, Schrader et al. 2013), and even increase students motivation (Childers, Jones 2017).
One of the first interpretations of presence in a virtual environment (Sheridan 1992) gave the opinion that presence can be separated into the three segments mentioned previously, that being physical, tele-presence and virtual presence. Sheridan also briefly mentions divine presence (luck, and unexpected events), however, this is not something that will be considered when dealing with remote education. With regards to remote education, physical presence can be defined as the evidence of the existence of the apparatus or its location. This is especially noticeable in remote labs when things such as web cameras and even augmented reality (Maiti, Kist, Smith 2016) are utilised in order to show the apparatus of the experiment as it is being completed as the results are being generated. To increase this feeling of physical presence, even electronic devices and microprocessors will be shown in an experiment even though no moving parts may be observed (Yazidi, Henao et al. 2011, Ionescu, Fabregas et al. 2013, Schauer, Krbecek et al. 2014, Siddiqui, Masarrat Husain et al. 2016).

The requirement for physical presence is important for remote laboratories, but not simulations. However, tele-presence, or the feeling of “being there”, as defined by Sheridan (1992) is an important factor for both. Tele-presence defines how immersive an experiment can be, or the feeling that the user is actually at the physical location that the laboratory is being held in. This can be hard to create when using a computer, however, virtual presence, the feeling of being in an environment created by the computer, is much easier to create.

In an attempt to measure the response to presence, it was mentioned that three methods that have been used (Sheridan 1994), those being to measure a
subjects’ response to changes on screen such as a ball coming towards the user, to see if a physical reaction or reflex occurs. The second method is to simply ask students to rank the degree of realism felt by students while completing the practical session, and the third is to determine if the student can discriminate between the real and virtual world, and to what degree extra factors such as noise in the system are required to decrease a students’ ability to differentiate the two. The reason for needing to measure the degree of presence in this way is that by nature, presence is a qualitative measurement.

Sheridan (Sheridan 1999) released another perspective on presence, one stating that presence is more about our perception of the reality around us, one that is capable of having many differing models all interacting in the same reality.

It was found (Nunez and Blake 2003) that with simulations, a user “experiencing the higher quality display will experience more presence” (pg.105). Although the paper did not focus on remote laboratories, research into the area of realism in remote laboratories is something that should be considered. Remote laboratories are capable of creating a simulated environment to present to the user (Carpeño, Antonio, et al 2017) in order to promote presence while the server still interacts with real equipment instead of simulations.

Nunez and Edwin Blake also showed that the degree in which presence became a factor was also influenced by the level of priming a student had undergone before the experiment, such that with maximum priming, the difference in presence is amplified, and is also decreased the less priming the student has undergone for the experiment.
With this known, it is important to note that remote laboratories must too show realism in their approach. Students who believe that the laboratory is real, and not just replaying previously recorded footage, often show an increased degree of investment in the laboratories, and show an increase in learning outcomes as a result of this.

It is with these things in mind that the uses of different media become important. While analysing the differences in the mediums that are available, it is reasonable to expect that the methods that students interact with different media affects the way in which they learn. Real world laboratories, simulations, batch remote laboratories and active remote laboratories all offer a different learning experience for the user.

2.4. Student learning

When observing the methods in which students learn, the definition put forward by Sigelman and Shaffer (Sigelman 2009) that learning is a relatively permanent change in behaviour or behaviour potential based off of ones experiences does not take into account the many methods described that show how people learn, or what motivates learning to occur. Classical conditioning (made famous by Pavlov’s dogs (Dickinson and Mackintosh 1978, Ziegler, Soni et al. 2012)) behaviour modification and Modelling (Delahaye 2011) are often seen as the three methods an individual uses to learn, but this theory does not cover the strengths and weaknesses of an individual’s learning style.

There has also been a model proposed (Riding and Cheema 1991) for observing the learning style of people in education, or in other disciplines. It was
proposed that the learning style of an individual exists on a scale, with Wholist-analytic on one scale and verbal-imager on the other. The Wholist being a person who views the bigger picture in a learning curriculum and the analytic preferring to break learning material down into smaller sections. In addition to this scale a complementary scale is used for verbal-imager, where a verbal learner learns from forming words and an imager learns from associating learning with more visual means. Both scales operate independently of each other, with an individual able to be at either end of each scale. (Riding and Cheema 1991) also proposed a Cognitive Styles Analysis as a method of assessing at what position in the scales an individual is placed.

David Kolb (1981, 1985) presented an opinion on learning for adults that put forward the idea that learning in adults changes compared to learning with children. What he proposed is commonly referred to as Kolb’s Experimental Learning Theory. He stated that learning involves four stages, concrete experience, reflective observation, abstract conceptualisation and active experimentation (referred to as feeling, reflecting, thinking and doing respectively)(Kolb 1981). The Learning Styles Inventory (LSI) put forward (Kolb 1985) identifies at what stage of learning an individual is on, converting the four stages to two opposing scales, those being processing (having active experimentation and Reflective observation at either ends of the scale) and perceiving (having Concrete experience and abstract conceptualisation on either end of the scale). Depending on where an individual sits on these two scales defines a learning style for this individual, those being:
- Accommodator: High in Concrete experience and Active experimentation.
- Divergers: High in Concrete experience and Reflective observation.
- Assimilators: High in Abstract conceptualisation and Reflective observation.
- Convergers: High in Abstract conceptualisation and Active experimentation.

Honey and Mumford also presented a method of measuring learning styles in the learning cycle they proposed (Honey and Mumford 1992). This cycle is similar to that proposed by Kold, in that it has a scale with four extremes, those being activist (instead of Concrete evidence), reflector (instead of Reflective observation), theorist (instead of abstract conceptualist) and pragmatist (instead of active experimentation).

Another learning style (Anderson and Reder 1979) proposed the theory that for a deeper level of learning to occur, learning material should be associated with what is already learnt. This process acts to reinforce what has already been learnt but also building on this knowledge instead of creating new knowledge. It also allows the learner to more accurately and faster retrieve the material from long term memory. Thus building on knowledge is better for learning that presenting entirely new information. This theory is also supported by (Hole 1853) who proposed the theory that learning must start at the individuals’ level of knowledge and then progress, instead of starting the learning process with the learner having nothing to build on, and therefore nothing to associate the learning with.
The learning style of an individual is an important factor when observing the retention of learning material, but motivation is also an important factor when considering what affects adult learners. It was proposed (Bye, Pushkar et al. 2007) that there are two learning styles that focus on outcome while finding motivation for learning, those being intrinsic and extrinsic learning. Sansone, Thoman & Smith found that traditional university aged students (late teens, early twenties) focus on extrinsic rewards, better responding to external influences such as a graded assignment giving external evidence of learning (Sansone, Thoman et al. 2000). Intrinsic motivation however focuses on motivation to learn a subject instead of being rewarded externally as a result of learning the material. While both motivating factors are present, knowing which will have the most impact on students has its benefits when designing curriculum.

Structure for the observed learning outcome (SOLO) is a scale aimed not to determine how an individual learns, but to be used as a metric to establish how a learners’ understanding of a material grows in complexity as their grasp of the material is made more solid. (Biggs and Collis 2014) proposed this scale as a tool to measure a students’ learning process. It consists of five stages, those being as follows:

- **Prestructural-Student does not understand the material, task is not approached appropriately**
- **Unistructural- Few or even one of the tasks are understood and picked up**
- **Multistructural- Multiple aspects of the task are understood and learnt, however are treated as individual tasks instead of as part of a whole.**
- Relational- All aspects are integrated into a single task, with each aspect being related and contributing to the overall task

- Extended abstract- The task is understood to the point where it can be generalised to other areas, and is reconceptualised to a much higher level of understanding.

It has even been suggested (Biggs 1996) that the above understanding can be used in order to easily assign a letter grade, such that the grades for A to F correlate to an extended abstract understanding, relational, multistructural, unistructural and finally prestructural understanding.

Other methods of assessing student learning have been split into six categories, those being skills testing, objective written, subjective written, performance tests, learning diaries and portfolio assessment. These methods aim to test or verify the current amount of learning that has occurred by a team or individual, and are powerful tools that can be used in order to better determine the level of knowledge that has been obtained in a learning environment.

Skills test is a basic form of learning assessment, but can be the most direct in ensuring learning has occurred. It involves observing the behaviour from the learner in what was taught to them. The example used by (Delahaye 2011) was that if aiming to teach someone how to repair a fault in a photocopier in under three minutes, a skills test would simply involve observing them solving this problem in under three minutes.

Objective written and subjective written tests follow a more traditional style of a written examination, with objective having a clear correct answer such as a
true or false question and a subjective written being presented in the form of an argumentative piece or essay, where there is no single correct method. An analysis of the accuracy of objective written tests was completed (Verhoeven, Hamers et al. 2000) with the aim of determining if it was possible to supplement performance tests with written tests without a loss in accuracy while determining the learning outcomes. It found that written tests were an accurate method of measuring learning outcomes of medical students and could be used to compliment the performance tests.

Performance tests assess the user’s ability to complete an objective within a given set of parameters, often to predetermined criteria. This is often done via an interview process or by observing the outcome or creation by the student. This process can also involve rating the performance of a student compared to a predetermined scale. This method has been used (Grantcharov, Bardram et al. 2003) to objectively determine the skill level of surgeons performing the required procedure on a simulation over an extended period of time.

Learning diaries encourage the learner to complete a higher level of analysis on their own learning outcome and objectives while completing the learning process. They also encourage the learner to complete a critical reflection on their own learning. This process encourages self-directed learning, and also causes self-reflection of the learning process (Nückles*, Schwonke et al. 2004).

Portfolio assessment is a means of collecting the learners’ achievements in a single source, and presenting these achievements to the assessor. Through the
use of a portfolio therefore, it is possible to have a way of presenting evidence of a specific learning outcome (Paulson, Paulson et al. 1991).
3. Design goals

3.1. Requirements of remote laboratory

The laboratory designed needed to conform to specific requirements to be able to reliably test the hypothesis for this project. It required the laboratory to be remotely accessible, as with all remote laboratories, but also incorporate a real world system. Because of this, specific design considerations were required. This section will cover those design considerations, and how they were overcome. The section will be separated into general overview of the requirements of the laboratory, then go into the methods used to incorporate a real system into the laboratory, as well as how students were able to access the laboratory.

3.1.1. General overview of the problem

The laboratory required students to be able to remotely access it, as well as dealing with the outputs of real world data. This created a unique problem in that a web interface was required, data logging and storage would be required and interfacing between multiple systems (real world data, logging equipment, and database) would also need to be employed in order to effectively create the remote laboratory.

3.1.2. Web interface

The web interface faced two primary challenges. It needed to be accessible for students at any time, and from any location, but it also needed to be set up such that either any number of students could access the laboratory, or a queue system was put in place to ensure only a set amount of students accessed the laboratory at any given time.
The advantages of a queue system is that it allows greater control over the time students access the laboratory, and ensures the equipment is accessible at any time, but it also comes with extra requirements, such as to have equipment that can reset to a pre-determined ‘zero point’ if required. Instead of doing this, it was instead decided to create a laboratory that would be accessible by any number of students simultaneously, and have no need for a reset ability. This was done by giving students access to both real time data but also to logged data from previous readings, meaning that if they missed a specific time that they were after data, it would be possible to log in at a later date and still have access to this data. In addition, if multiple people wanted access to the same data, they can all be available in lab to view it.

Making the lab available to multiple devices proved to also be a challenge. While many laboratories use programs that are native to a single operating system (flash, for example), it was decided that a laboratory that required no previously installed software would be created. This meant that every section of the laboratory needed to be run in a way that did not require java, quicktime, flash or many other programs. More information on the method used to construct the laboratory in this way will be further expanded in later sections of this document.

3.1.3. Storing Data

Since multiple students had access to this laboratory, it was required to allow them to view logged data as well as live data. This meant that a window of both two and twenty-four hours of data were made available to the students at all times. In addition to this, summaries of all previous days’ data was also
supplied. Data needed to be stored in a secure and reliable manner, so a MySQL database on the web server was selected. Considerations for a MySQL database was that it would reliably and securely store data, while also being able to be accessed through a web server running PHP.

3.1.4. Data logging

Data logging was done in a location away from the web interface server and therefore required a different computer to handle logging and sending this information to a computer. It was also required to have this data logged while still allowing other equipment to work with the hardware being logged, so a solution that allowed the remote laboratory system to harmoniously work with the pre-existing system was required.

3.1.5. Behaviour tracking

The remote laboratory being designed needed to be usable as a research platform, and therefore extra considerations were required. The use of google analytics was a consideration on how best to track users’ behaviour, however this required the web page be run in either html or PHP. While this was not an issue, it still remained the case that design choices needed to be updated to reflect the requirement of these web interfaces to execute scripts required for this research.

3.2. Realism in remote laboratory

A design consideration that was required for this remote laboratory was how to properly show a system that exists in the real world. By altering a system, it could be seen instead as a model, therefore removing the desired learning
objective of the laboratory. With this in mind a way of accessing data from a real world and fully operational system was required.

3.2.1. How this could be achieved

In order to present students with data from a working system, a method of logging the outputs of this system was required. This logging equipment needed to be able to collect its own data in real time, while also not changing readings already being taken or modifying the behaviour of the system.

A requirement therefore was to create a device capable of interacting with a currently working system, without modifying this systems behaviour. This presented a unique challenge, as any implemented software and hardware needed to both act in unison with the currently designed system, while running its own independent functions. By design, it was a goal to have this system also be modular such that any required system could have this laboratory hardware added to hopefully make a new laboratory.

3.3. Student access of remote laboratory

Looking at the way students access remote laboratories is also an important step. When asked which device students use to support online learning, the below figure was developed.
It can be seen from this figure that while apple devices are commonly used (meaning any Microsoft or Linux only software would be insufficient), the Samsung mobile device was also used by students, showing a need to have multiple different devices, operating systems and hardware considerations able to access any data generated is an important design consideration. Students accessing data from an apple product need to be able to see the same information as those accessing the data from a Sony, Samsung or other android device. This also only accounts for mobile devices, Windows and Linux desktop or laptop computers too need to be able to access the data.

Due to this, design considerations around screen size and operating system became important. Log files were exportable and could be opened by a wide range of applications, graphs needed to be clearly displayed and easily viewable, while still allowing pinch zoom that many mobile devices include.

Therefore, a considerable amount of design time was used to ensure that an option could be built that not only could any device use, but any operating system using any web browser.
3.3.1. Access without installs

Due to the large number of users utilising different devices, all with different operating systems and version numbers, it was decided early in the design stages of this laboratory that a method of allowing students full access to all laboratory functions without installing additional software would be beneficial. This goal would therefore have a large effect on design considerations ranging from the user interface, the web interface software allowed, the method data would be stored and called. All of these decisions had to take into consideration how a user would access and view the remote laboratory data from a web browser within this system if no additional software could be used.

This decision did have the benefit of not requiring an installation package to be created. This would have led to an ongoing requirement of offering continuing support to users installing the software package, something to be avoided if possible.

3.4. Hardware Requirements

The hardware used to create logged data was a pre-existing system tracking the energy generated by solar panels in a renewable energy system. Due to the fact that all hardware was being used for other projects, a solution needed to be created that could wait for communication between all devices to finish before sending commands for the remote laboratory.

3.4.1. Requirements of working with this hardware

The current hardware could only output a single data point every ten minutes, making its sample rate extremely slow for the desired application of the
remote laboratory. It had a RS232 digital logic converter connecting the hardware responsible for creating and storing all data from the inverter and the physical outputs of the solar inverter, and it was decided to use this point to connect the remote laboratory data logging hardware. To accommodate this, the logging hardware for the remote laboratory converted the RS232 connections to USB connections, as it was able to interface with these connections much easier. This allowed the remote laboratory hardware to act as a bridge between two systems, while also making data logging requests of its own.

3.4.2. Required hardware to be purchased

The laboratory required two unique systems to be set up, those being the logging hardware and the web server. Since the web server was created from a computer already available, only the logging hardware was required to be purchased for this application. It was decided to purchase a Raspberry pi (model 2B) as it was able to interface with the pre-existing hardware, had enough inputs to work within the design perimeters and could easily connect via Ethernet to the network. It was also possible to program all required scripts and batch files using the raspbian operating system that came pre-installed.

3.5. Software Requirements

While the issue of accessing the remote laboratory has already been mentioned, and the requirements of the raspberry pi to be able to log information while not interfering with the pre-existing data too has been discussed, there were other software considerations that were required to adequately design and build the system described.
3.5.1. Operating system considerations

The operating system that was used for this project was Linux (both Raspian and Ubuntu). While it would have been possible to use other operating systems, native support for python, the LAMPs (LINUX APACHE MYSQL PHP) software suite and most resources used requiring Linux architecture meant that the decision became simple once this was taken into account.

The data logging hardware ran on Linux, as python was the main programming language used, but also due to the face that a raspberry pi was to be used, which comes with Linux pre-installed. This made the decision to remain with the Linux operating system justifiable. While there exists a windows based raspberry pi platform, it was unclear how much support would exist for it, and as there was a significantly larger resource base from Linux users, this also influenced the decision. Since the web server utilised the LAMPS software package, making Linux the chosen operating system for this server as well.

3.5.2. User Download/bandwidth considerations

The ability for students to access the data considered, it was aimed to create a laboratory that used minimal bandwidth as this would allow for students with minimal data to still feel comfortable accessing the remote laboratory. Consider that mobile phones can access the laboratory and therefore data limitations needed to be considered. This was solved by making the laboratory able to function without the need for video and images were too kept to a minimum. This minimalistic approach also ensured all required data was easily available and immediately recognisable.
By not including a live feed from a video feed, another method of proving to the student that live updates were occurring was required. In order to demonstrate this to the student, it was decided to have data generated while the user was present in the laboratory be graphed, with all new data being updated on this graph such that those students accessing the laboratory would be able to immediately see that with the passage of time, more data became available to them.
4. Methodology - Research foundation and laboratory design

4.1. Overview of project preparation

To complete a project of this scope, a firm research plan needed to first be established. In order to do this, the project was separated into multiple sections, each identified as a milestone of the project. Firstly, a strong research foundation needed to be established. This involves analysis of current literature, and modern experimental techniques. After this general overview, expert knowledge of current remote laboratories and simulations were also established. After this, hands on experience was gathered to ensure familiarity with currently existing laboratories. Once this was completed, experimental procedures could be established. This involved both the design and construction of the research platform as well as establishing research participants. Finally, the methodology of gathering results must be established, as multiple sources of information must be gathered and analysed. These milestones therefor are listed below:

1. Research foundation
2. Laboratory knowledge foundation
3. Laboratory design
4. Laboratory building
5. Identifying research participants
6. Gathering and analysing results

Each of these milestones will be further discussed in the following sections.
4.1.1. Research foundation

To complete this project, the ability to correctly plan and research the way in which students approach learning in a remotely accessible renewable energy system would be vital for a successful project. Expert knowledge of current research in the field of remote laboratories would be required, as well as an understanding of research trends and methods used in the field.

4.1.2. Literature review

First the literature available in remote laboratories was analysed. This literature review involved research into multiple different areas, including remote laboratories, simulations and current practical class methodologies. It also looked at current opinions in pedagogical research, as highlighted by the Clark-Kozma debate (Clark, 1983, 1994 Kozma 1994, 2000). In order to gain as much of a solid knowledge foundation as possible, the literature review also involved researching into other relevant areas such as presence in education as well as perception of reality and perceived learning objective.

In order to gain the largest amount of base knowledge possible, research into the currently publishing academics, and their publications was required. In this sense, it was decided to look up not only papers based off area, but papers based off of research interests of relevant academics. This allowed for both a broad analysis of the topic, as well as a magnified view of relevant knowledge for this project.
4.1.3. Attend Collegiums

Knowledge of current leading edge research was required, and to gain this, multiple conferences were attended. This aided in a deeper understanding of topics related to this field, and to this project.

4.1.4. Possible future work

Once knowledge of the work was being completed in remote laboratories was being undertaken, it became apparent that a need to understand future work was required. This would allow for the knowledge of what expected results were being compiled, and to know what research publications and new information to be observed.

4.2. Laboratory Knowledge Foundation

This step involved testing laboratories currently being employed by universities as education tools. The reasoning behind this was to analyse what in the laboratory was effective, how students accessed the information and to have a better understanding of remote laboratories from a user’s perspective. For this step, it was important to gain hands on experience working with remote laboratories.

4.2.1. Testing remote laboratories

Laboratories from UTS (University of Technology Sydney) (Lowe, D., et al, 2012) were used for this step, focusing on laboratories addressing physics problems such as a bending bar experiment that displayed concepts such as tension and compression in a physical material, as well as laboratories aimed to display the concepts of transfer of momentum via the use of shake plates.
The exposure to remote laboratories, as well as the opportunity to interact with these laboratories was a required step, as it ensured exposure to currently existing remote laboratories, and also increased the understandings of concepts such as presence in the laboratory, and how such concepts may influence the learning experience. It was also an opportunity to critically analyse the experience of completing a practical experiment in a remote format. It also further solidified the knowledge gained from analysing literature, as it gave the opportunity to replicate the experience that had up until that point only been theoretical knowledge.

4.3. Laboratory Design

This section will cover the software design of the laboratory. It will primarily discuss software as this needed to be designed in a very specific way to allow design goals of the remote laboratory to be realised, mainly allowing any device operating any web browser access to the laboratory.

It was decided to have a laboratory that presented solar data to students in a live, continuing updated manner. A solar panel connected to a solar inverter generated an energy output (read in joules) that was presented to the students. The purpose of this experiment was to familiarise students with the expected outputs of industrial equipment, and to gain a further understanding of the conversion between joules and watts over a known time period. It also demonstrated to students the inherent noise presented in most electrical systems. An example of the Arora PVI-3.0 inverter configuration is given in Figure 2. This was the inverter selected for the laboratory. It has a maximum output of
3k joules when connected to solar panels, can be connected to additional units and communicates to the end users equipment via an RS232 input.

Figure 2: Inverter configuration during standard operation (Power One, 2009)

The inverter automatically calculated joules generated by the solar panel and outputted this information to the end users computer when the computer requested this information with a specific string. The inverter specifications are listed below in Table 1.
Table 1: PVI-3.0 Inverter specifications (Power One, 2009)

<table>
<thead>
<tr>
<th>Description</th>
<th>PVI–3.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal output power</td>
<td>3000 W</td>
</tr>
<tr>
<td>Grid voltage, maximum range</td>
<td>183 to 304 Vac</td>
</tr>
<tr>
<td>Grid frequency, nominal</td>
<td>60 Hz</td>
</tr>
<tr>
<td>Grid voltage, nominal</td>
<td>277V single phase or 240V split phase (default) or 208V single phase (setting required)</td>
</tr>
<tr>
<td>Nominal output</td>
<td>10.8/12.5/14.4</td>
</tr>
<tr>
<td>Max. output current</td>
<td>12/14.5/14.5 Arms</td>
</tr>
<tr>
<td>Output over current protection</td>
<td>15/20/20 Arms</td>
</tr>
<tr>
<td>Maximum efficiency</td>
<td>96.8% (96 EURO)</td>
</tr>
<tr>
<td>Size (height x width x depth):</td>
<td>787 x 325 x 208mm</td>
</tr>
<tr>
<td>Weight</td>
<td>18 kg</td>
</tr>
</tbody>
</table>

It was decided to create a device that could communicate with the inverter to provide the outputted information to students in real time. With this decision came many design considerations that needed to be considered. These are discussed in the following sections.

4.3.1. Analysis of current software packages

This step involved looking at current software packages available to assist in the designing of a remote laboratory. The SAHARA labs package (Lowe, Machet et al. 2012) was originally considered, as it would be robust enough to handle the requirements of the laboratory being designed.

The other option considered was to design a solution in house. While this option would theoretically take longer developing, it allowed a greater degree of...
control over almost any aspect of the laboratory, and allowed for design decisions to more easily be implemented.

SAHARA labs was a software suite that allowed for a framework that could be used to implement a remote laboratory, and was designed specifically for this task. It operates by separating the laboratory into two distinct sections, those being the web interface and the laboratory architecture. The laboratory architecture allows the laboratory hardware to interact with the SAHARA software, allowing direct control over the required hardware. It allows for functionality such as resetting the hardware to a pre-determined position to ensure once a user is finished work on the laboratory, subsequent users have a predetermined hardware setup. This also allows for a reset position to be used during the laboratory.

The web interface is responsible for creating the online resource that students in the laboratory directly interact with. It handles creating a scheduling assistant to ensure students are given allocated times, and that they can book sessions in advance. It also handles video encoding for a web camera, allowing for multiple video formats to handle changing bandwidths, and for hosting the web page.

While SAHARA labs would be an appropriate choice for other laboratories, the amount of functionality it offered would not be required. An example if the scheduling system, which assumes multiple users cannot access the remote laboratory simultaneously. This design consideration was not needed however, as a laboratory allowing multiple simultaneous users could have been developed for
this application. It was decided that if this was possible, it would be done. In addition to this, there exists software packages such as LAMPS (LINUX APACHE MYSQL PHP), which allow for all aspects of the laboratory to be directly controlled in a much easier fashion.

4.3.2. Determine exact requirements of the laboratory

It was at this stage that the choice between an active or a batch laboratory was decided. A batch laboratory allowed for users to analyse past, logged data, which was seen as beneficial. However data being generated in real time was also required. Due to these design requirements, a batch laboratory with elements of active laboratories was designed. This hybrid style design was chosen as it allows for live updates of renewable solar energy generated to be presented to the user in real time, but to also include snapshots of the last two hours and twenty-four hour periods. If a user desires more information, logged files containing the daily power generated as well as lifetime power were also made available.

4.4. Laboratory Building

The requirements of constructing the laboratory needed to take into account both the pre-existing hardware that would be analysed, as well as any peripheral hardware to be designed. These aspects of the build will be further discussed in the following section.

4.4.1. Analysis of currently available hardware

The laboratory in question was set up to communicate with a system at Deakin that was already functional, and therefore an understanding of the protocol between the two devices (computer and inverter) was required. This
would allow the laboratory hardware to both log its own data, as well as allowing the system to continue standard operations. This was required as a major part of this laboratory was that it introduced students to a system that was functional and already implemented. This required the hardware to be able to collect data without affecting the equipment already logging renewable energy data.

This step also required an understanding of the protocol between the currently existing hardware and the solar inverter be established. The reason for this was that the device must be manually polled for information, and such enquiries needed to be easily executed. It was decided to create a batch file that was capable of handling this request, meaning that if the protocol ever changed, or the laboratory was to be modified for another application, this batch file could be modified to suit the new hardware, without having to modify any of the laboratory communication software.

4.4.2. Analysis of the requirements for conversion to remote laboratory

This step involved looking at hardware options that would allow for the laboratory to monitor the solar inverter output, while being able to upload this information to a server and also connect to logging equipment already being utilised. Multiple devices at this stage were considered, allowing for cost, physical size, availability and ease of programming.

Outputs files of the solar inverter were updated every ten minutes, leading to the requirement of having lab specific hardware capable of handling requests for data while not interrupting this communication. This was handled with a raspberry pi.
4.4.3. Lab access without installs

The remote laboratory used in this study needed to be designed to make accessing the laboratory as easy as possible for the students. The laboratory would in no way be formally assessed by students, and it was decided to ensure the laboratory worked on the wide range of devices used by students studying electrical engineering. By having a laboratory that was not formally assessed, students with any issues accessing the laboratory could possibly avoid re-attempting to access the laboratory once the issues had been resolved, meaning that the laboratory needed to be as easy and reliable to access as possible, over the multiple devices, operating systems and web browsers expected to be accessing the laboratory. Due to this, a method of allowing multiple devices to access the laboratory without needing to install any additional software was created.

With the idea of creating a server able to handle multiple different access types, it was decided to use the LAMPS package. This enables the server to run dynamic web pages without the need to have extra software installed, and also enabled a MySQL database to be used not only to store all data, but to be used in order to set flags high, and to therefore communicate with the raspberry pi. Each component of this design needed to be able to communicate with the other, and to effectively manage data flow between themselves. This laboratory also was required to function as part of a larger system (that being the solar inverter) in a way that did not interrupt the data gathering from that system. A basic overview of the functionality of all components directly related to the remote laboratory is presented below in Figure 3:
Figure 3: Shows the overview of the hardware chosen and its purpose in relation to student access

The strength of this layout is that it allowed the end user to view all data in the database from an HTML page, with PHP handling all requests to the database. This was set up in such a way that all data was securely stored, and that the database was not accessed directly by the student, but instead only responded to scripts the student called, therefore removing the ability for the student to interfere with, and possibly modify the database logged data. This layout was selected as it easily allowed for a web server to be created that did all processing server side, therefore not requiring the user to do any processing, leading to more control over the exact content they had available, as well as control over the format this content was presented.
The raspberry pi was responsible for querying the solar inverter for the exact data being generated. This was then sent to the database using the User Datagram Protocol (UDP) protocol, an alternate to the TCP/IP protocol. The database (or more specifically the computer the database is on), running linux, then receives the data, formats it into a usable format, timestamps the data and stores it in the database. The joules generated over the last ten seconds is what is received, and therefore at this stage the watts generated over this time is determined, and this is also stored.

What this means is that every ten seconds a data point is generated, leading to a new row in the database being created, containing a specific row ID, joules and watts generated over the last ten seconds and the year, month, day minute hour and second this data was generated. This method of storing information means that when data is called, the exact time information can easily be found as well. In addition to this, the method used to display the x axis of the logged data graph (displaying time data was collected) requires information to be called from the database, meaning that this time information must be generated and stored automatically.

This also becomes important when considering the data logs, as the data averages one data point every ten seconds, but can often be generated at a rate faster or slower than this, often by a few seconds. What this means it that if only the solar power output was stored, there would be no way of accurately knowing at what time the data was generated, as multiplying ten seconds by the number
of data points created would not be as accurate as having the current stored information.

The web server in this setup was required to allow multiple students to access the data at any given time. This meant that all data displayed had to be unique to the student viewing it, instead of as a static web page, however students accessing simultaneously would still be exposed to the same data as it was updated live. As renewable energy data was stored in a database, access time dictated what students saw, however if accessing over an extended period, these differences would be single data points, and therefore not disruptive to students experiences. What this eventually meant was that the time students began accessing the data did not inhibit their experience at a later time.

By having a server with separate hardware to the data logging hardware (raspberry pi), the data logging hardware needed to constantly be in communication with the server. This was done through an Ethernet port, and by ensuring both setups had a static IP address. Both devices running Linux were set up so that a script establishing communication between the two was executed on start-up, leading to a system that was capable of re-establishing communication, and therefore lab functionality even through power failures. This was also done automatically, meaning that the laboratory did not require constant monitoring to ensure it was fully operational.

Html coding was required to provide an interface for students to access the laboratory. It allowed for a catch all access mode for students, with scripts running from PHP able to interface with the required databases. This PHP
programming language was used in this case as it allowed for access of specific database information quickly and easily, with plenty of support available. Since this web server architecture was developed in house, a design needed to be developed that allowed for ease of programming, as debugging and implementation needed to easily and efficiently occur. Having a large amount of online support for html, PHP and general MySQL database design was essential for the completion of this laboratory.

One of the benefits of setting up a system such as this is that programming for specific operating systems or more importantly different devices is not required. Oftentimes creating a mobile interface is a requirement for students wishing to use a laboratory from a mobile device, however for this laboratory that is not the case. Due to mobile devices often containing pinch to zoom, and designing around the concept of having information shown in easy to access locations, a mobile device is adequate to see the information in this remote laboratory.

The design overview of the laboratory involved using updated database values to act as flags for interacting with other devices. The html page was able to view and stare values in a MySQL database, meaning that advance functionality could easily occur, with extra features being added at a later date if required.
Figure 4: Shows the comparison of the web site accessed from a phone compared to a computer browser

As can be seen in Figure 4, the access device chosen does not affect the user experience. Things like navigation through specific windows, accessing live updated data and viewing the logged information (as is shown in Figure 4) are all still very possible. This homogeneous access was also a way of solving the design goals for this laboratory, as it meant that students accessing the laboratory via multiple devices would not lead to issues of debugging and redesigning for different devices at a later date.

Another benefit of this design is that it allows multiple users to access the remote laboratory at identical times. Parallel access to this laboratory was
handled due to the fact that the web server can handle multiple requests from users at any given time. This removed the need for a scheduling server.

The methodology discussed contained a further two section, those being the identification of research participants as well as the requirement of gathering and analysing results. The method used to gather results extended beyond simply asking users to give feedback on their experiences in the laboratory, and while this step was taken, it was possible to further track their behaviour. The implementation of such laboratory functionality in order to create a method of analysing students’ behaviour and access patterns will be discussed in the next section.

4.5. Identifying research participants
The process of identifying research participants involved analysing units that covered relevant subject areas and had a practical element that would be suitable for the designed laboratory. After appropriate units were identified, unit chairs were then contacted to discuss the possibility of incorporating the laboratory into their subject.

There was a total of four units matching this criteria, all incorporating renewable energy systems or basic electrical systems, and the analysis of the outputs of a solar inverter. All research participants were students enrolled in these four subjects, and were studying either undergraduate engineering or postgraduate engineering. The exact method of identifying research participants is significantly expanded below, in section 5.3.1
4.6. Gathering and analysing results

Results were gathered primarily through surveying students and analysing user information as they interacted with the laboratory. Survey results were primarily written responses, or responses from a likert scale.

Once results had been collected, a method of analysing written responses was required. This involved grouping responses that were similar and using the total percentage of responses to compare the overall view of the research participants. Responses on a likert scale were given a weighted average, and compared together using this number. The exact method of gathering and analysing results is discussed below, in section 5.2, 5.3.2 and 5.4.
5. Methodology - Survey and questionnaire

For a project of this scope multiple feedback methods were utilised. It was decided with this project to gather feedback from students in two forms, those being written responses and numerical responses from a Likert scale. In addition to this, information on how students interact with the laboratory was also to be collected.

Design of the survey was broken into 8 questions. It aimed to receive both qualitative and quantitative answers, and therefore had a mix of checkbox questions and written responses as can be seen in section 12.1.3 (appendix 1). For this survey, it was aimed to gain feedback three specific areas, those being the perceived learning objective of the remote laboratory, or perceived laboratory focus, the degree of realism the students felt the lab displayed, both of the equipment being used to generate data and the data itself, and the amount of presence students felt whilst completing the remote laboratory.

In addition, questions such as Q1 (appendix 1 – section 12.1.3) were aimed to receive general feedback about the laboratory in the aim that students would present information on either how we could improve the laboratory, or how they approached learning on the laboratory. This allowed for the students to give us more general information about their experiences. This information ideally could also be used to supplement the findings in the above three research areas.

Tracking user behaviour while competing the remote laboratory also gave an insight into things such as students’ access times thorough the semester, access devices and web browsers, as well as the number of unique visitors completing
the remote laboratory. This was done as a way to gather information on the way students interacted with the remote laboratory both in individual sessions, and over the entirety of the semester the laboratory was available to them.

As with the previous methodology section, the methodology has been separated into separate sections. These sections are as follows:

- Ethics training
- Survey design
- Circulating Survey
- Gathering user behaviour data

The ethics training section will cover the compulsory training that was required to be completed in order to complete the research, while the survey design section will cover how the survey was structured, with a brief analysis of the questions that were presented to research participants and why they were presented in this way.

The discussion on circulating the survey will cover selecting research participants and how they were presented both with information on accessing the remote laboratory as well as any feedback, and finally a section on gathering user data, which covers programs used to analyse student behaviour in the laboratory, and how these programs were implemented.

5.1. Ethics training

Ethics training was an important (and mandatory) aspect of this project. Not only are there legal requirements, but human research ethics training also
presents the knowledge required to properly apply for a research project involving
research on humans. For a project of this scope, ethical approval was applied for
and gained with little issues. This involved a training beyond the required general
ethics for a higher degree student. This is due to humans being involved in the
research process. The results gathering process was deemed to be low risk, and
therefore low risk ethics approval was achieved.

5.1.1. General training

General research ethics training was a prerequisite for the subsequent
human ethics training. It was completed previously to low risk human ethical
training, and included the basics of ethical research.

5.1.2. Human research

This training was completed after ethics in research training, and was a
required step for this project. This training included the required information for
application of ethics approval forms, as well as a general overview on research
involving human participants. As the research included having research
participants complete a questionnaire, this level of training was a requirement.

5.1.3. Ethics application

The ethics application for this project involved determining exactly what
steps would be required for this project, who would be asked to complete the
survey, what emails would be sent to students, including reminder emails, and
how data would be stored after collection. It also included the methods that data
would be stored, to ensure secure data. While all research data collected did not
involve identifiable information as all information that could be used to identify
participants was removed, this was still an important step to consider. The form was filled out and submitted prior to allowing students access to the survey as to comply with the ethics requirements.

5.2. Survey Design and question selection

The survey designed was primarily designed to determine the following pieces of information.

1. Students’ perception of the learning objective for the laboratory and the laboratory focus
2. Students’ perception of presence in the laboratory
3. Students’ belief in the validity of the data being presented

The survey was also set up to allow general feedback for the survey. These questions were often written response to allow students to put forward their opinions on the laboratory, allowing them to give feedback of the laboratory and to present general results and more information on their experiences in the laboratory.

To gain information about students in the laboratory, eight survey questions were developed. A breakdown of their relevance to the laboratory is given in this section. All questions are available in the appendix (appendix 1 – section 12.1.3). Due to the survey structure, it was possible to obtain data from both Likert scale questions and short written response questions. In addition to this information, true/false of agree/disagree checkboxes could have be utilised, however it was decided that this functionality would not be required.
The survey was set up in a way that students would be given a variety of questions designed to allow students to provide both numerical data such as their response on a scale, as well as short written responses so that all opinions presented by the research participants would at some point be put forward.

For learning objective one, that being to determine the students’ perceived learning objective of the laboratory, and the laboratory focus, the approach to surveying students was twofold. It has been observed in previous literature (Lindsay, E., Liu, D., Lowe, D., Murray, S., 2007) that when asking students for their perception on a learning objective, they will often provide lab specific responses, learning objectives that apply to only the completed laboratory. This is in comparison to what could be seen as the required learning objectives as a competent engineer. An example of this would be gaining exposure to the types of electrical equipment an electrical engineer must be fluent in using would be a learning objective of a first year electronics practical session, however a laboratory specific learning objective would relate to only one laboratory, and be something such as measuring the peak voltage output of a sign wave.

It was decided that in order to encourage students to provide both their lab specific learning objective or laboratory focus, and an overall course learning objective, students would be encouraged to answer a written response on what they believed the learning objective of the laboratory was, as well as answer on a Likert scale their perception of laboratory focus from a list of pre-determined objectives. The responses allowed were very little focus, little focus, average focus, large amount of focus and specialised focus. These pre-determined
objectives reflect the research completed (Lindsay, E., Liu, D., Lowe, D., Murray, S., 2007) that found the perceived focus of a laboratory between specified learning objectives change depending on the educational medium. By providing these learning objectives, it allowed the results from this study to be compared to work previously undertaken.

It was decided that the written response question should be presented to students first, as if they observed the pre-determined list of laboratory focus topics it would likely affect the responses gathered in subsequent sections.

Learning objective two looked at students’ belief in the validity of data being presented to them. This also linked to their belief that the equipment was real. This learning objective aimed to analyse the established reality that students perceived while analysing data in the remote laboratory. While data was being presented to them, it needed to be established if students relied on the accuracy of the data.

To accomplish this, questions were asked primarily using a Likert scale with strongly agree, agree, neutral, disagree and strongly disagree as the allowed responses. Questions would often be asked in two different formats, with a student expected to agree in one format and disagree in another. An example of this would be a question such as ‘The equipment was real’ and ‘the equipment was computer simulated’. A student believing in the validity of the laboratory equipment would theoretically agree to the first question and disagree to the next. This style was also repeated for questions relating to validity of data, where they were presented to students in two distinct, opposing questions. In this
instance, ‘The data was real’ compared to ‘the data was computer simulated’. For the full list of questions, refer to appendix 1 – section 12.1.3.

Learning objective three and learning objective three were often linked in the questions being asked. While there was a specific question that asked students if they felt physically present in the laboratory, a deeper understanding was required. Presence in a laboratory setting looks at a students’ belief in the immersion of the laboratory, and therefore if a student did not feel presence, a method of establishing why or why not was required to be implemented.

To do this, again a Likert scale was used asking if the user felt presence, with the strongly disagree, agree, neutral, agree and strongly agree options given. Questions such as ‘I felt like I was physically present’ and ‘I felt like I was in an environment created by a computer’ also aimed to establish the students’ feeling of presence.

Finally, short answer questions were used to allow the users to provide written feedback about their experiences in the laboratory. General questions such as ‘how do you feel the laboratory could be improved’ were implemented with the intention of allowing research participants with the opportunity to provide feedback related to their opinion of the remote laboratory. This was done both to analyse the students’ behaviour in the laboratory, but also allow research participants a chance to provide data that could potentially be useful for an analysis stage of the laboratory.
5.3. Gathering Survey Data

This Section will cover the method used to identify research participants as well as circulating the survey to these participants. It will firstly cover the unit’s research participants were enrolled in, the current access modes offered by these units, either remote or on campus, and the subject’s relevance to the remote laboratory. After this, the method used to inform students of the survey will be discussed, as well as how the survey data was both acquired and stored. This is due to the requirements of low risk research involving humans for research data both being collected and for being securely stored.

5.3.1. Identifying Research Participants

When identifying the possible research participants for this study, it was required to determine classes that taught material similar to what was the laboratory was designed to inform students. After classes were identified, unit chairs were approached to assess if the laboratory could be incorporated into their curriculum.

The laboratory was presented to students as an extra resource, not a mandatory laboratory. This was done to ensure students would not be advantaged/disadvantaged by the laboratories availability.

The participants for this laboratory were selected based off of subjects they were currently enrolled in. The subjects selected were done so in order to align the subject material being taught to the laboratory. Due to this, many of the participants were enrolled in electrical engineering degrees. Overall, four subjects
were selected over a two year period. This was to allow the greatest number of students to access the laboratory at any given time.

Subjects were selected based off of a selected few criteria. The subject needed to have subject material related to power generation or renewable energy. This meant that students were primarily from undergraduate or postgraduate electrical engineering disciplines, however some students from the mechatronics discipline were also presented. The subject also needed to have a laboratory component that allowed for the remote laboratory to be implemented.

A discussion with unit chairs was had to identify if specific units would be applicable. From these discussions, a total of four subjects were selected. All students from these subjects were selected. All students from these subjects were invited to participate in the research project.

5.3.1.1. Identifying units to implement laboratory

This section will cover the specific units selected in which subjects were chosen. It will include a brief description of the unit, as well as the relevance to the remote laboratory. In total, four units were selected, with students from all four units being given access to the remote laboratory. The units selected often covered topics such as renewable energy systems, and offered the laboratory as supplementary to the main learning material. For the purpose of this research, the remote laboratory access was granted to students during the very first week of their studies, however there were instances where students were offered the laboratory as an example of content relevant to an assessment piece, or in a unit where the initial topics were not relevant to renewable energy systems. In these
instances the laboratory was only offered to students in the weeks that it was relevant to their studies.

The first unit to be discussed in this section was a unit in which students were given access to the remote laboratory was offered both as an on campus delivery as well as online. It was a post graduate level subject that required no prerequisites and therefore could be taken by any masters students enrolled in the course. The subject had a total of 55 students enrolled, with all enrolled students being given access to the laboratory. The class had a total of three contact hours per week, being separated into one hour of formal classes, and two hours of laboratory or project work. In terms of content, the unit aimed to deliver information regarding renewable energy systems including solar energy systems, but also wind, hydro, geo-thermal and biomass. The primary focus however was on the wind and solar systems.

The relevance to the remote laboratory for this subject was in the fact that it aimed to introduce students to controllers for renewable energy systems such as wind power and solar power, as well as an introduction to power electronic converters for these renewable energy systems. The laboratory provided students with a visual indication of the energy generated by a solar system, and therefore show students an example of the output of such a system. The students were also exposed to distributed generation, micro grid system and energy storage systems as part of their studies.

Overall the unit content aligned with the learning objective of the remote laboratory, that being to expose students to the renewable energy solar system
and to be able to analyse the output signals in real time. This would have been beneficial for the students looking into renewable energy converters, as this laboratory exposed them to the outputs of an inverter before they were required to design and model a renewable energy system.

The next unit to be discussed included a total of 37 students. The unit was offered as a post graduate level course, requiring all students to attend a total of three hours class per week, with the three hours being separated into one hour of traditional lectures and two hours of group work. The subject was offered as both on campus and remote.

Students were given access to the laboratory in the early weeks of their course, having the ability to access it at any time. As was common, the unit coordinator informed all students they had access, and an online link was posted on the unit’s web page. Students were invited to access the laboratory in their own time, and after sufficient time had passed an email was sent to all students with links to both the laboratory and the survey.

The subject covered topics such as energy efficiency, and strategies to assist in the development of sustainable energy systems. Students were required to complete energy efficiency calculations and to analyse renewable energy data. They were also tasked with analysing demand management for residential, commercial and industrial applications. The laboratory was offered to students as a way for them to analyse the output energy of a single solar inverter to allow them to analyse the expected power outputs of such a system and to be able to use this knowledge to assist them in choosing an appropriate solar panel system.
for possible application, including residential. The laboratory also assisted them by providing another example of renewable energy data for them to analyse. This produced further exposure for the types of outputs they would have to design around, as well as the hardware they would have to use to design potential residential renewable energy systems.

Within the undergraduate degree, there were two units in which the remote laboratory was offered. The first of these two units to be discussed was a required unit for all engineers studying towards both the Bachelor of Mechatronics Engineering and Bachelor of Electrical and Electronics Engineering. The unit was offered both to on campus students and to those studying remotely. Students studying in the on campus mode were required to attend two hours of formal lecture per week, a single hour of tutorial and a three hour practical session every third week. In total there were 59 students enrolled in this unit.

Students in this unit were required to study both analogue and digital systems, with the analogue systems being introduced in the second half of the study period. Due to this, the laboratory was introduced to the students in the second half of the semester. The lecturer for the unit introduced students to the laboratory by providing them with a link to its location as well as the instruction manual, which was posted in the online resources for the subject. This was done to allow those students studying the subject remotely the opportunity to also view the renewable energy data. The intention of offering this laboratory was twofold. Firstly, it allowed for students who may not have gained exposure to renewable energy systems in their degree to analyse the outputs of a solar energy system for
what could be the first time in their degree. This allowed students to both analyse a renewable energy system, and to link their current foundation knowledge to analogue system to a real world renewable energy system. The other advantage of offering this laboratory was to allow for students to analyse the outputs in terms of an analogue system. It provided students with a context in which to ground their engineering knowledge.

The final unit that this laboratory was offered in was a second year undergraduate electrical unit. It was offered to undergraduate engineers studying both the electrical/electronic major and the mechatronics major. It was also possible for students from outside of these majors to take the subject as an elective. In total there were 84 students enrolled in the class, and all of these students being granted access to the remote laboratory.

Students were required to attend 1 hour of classes per week and a 3 hour practical session every fortnight. They were also required to attend a 1 hour tutorial session every fortnight. The subject aimed to expose students to a wide range of renewable energy systems, and gain the knowledge and experience to deal with the varying types of systems. Both on campus and remote students were offered this subject.

As with all other units, the remote laboratory was offered to the students within the first few weeks, however this subject offered the laboratory to the students in the third week of the trimester. This was done in order to align the teaching material with the laboratory. Students were required to analyse renewable energy systems to eventually be able to model their own system. They
were required to produce on grid and off grid solutions. The intention of the laboratories inclusion in the subject was to assist students in visualising outputs of a renewable energy system, as for some this would be their first time working with such systems, even if primarily through simulation. They were also shown visually that if only solar power were to be used, they would need a failsafe for times when solar power was not being produced. This encouraged students to look into more than just solar energy as a renewable energy system. Some students were able to use the data gained from the laboratory for their written assessment.

A common trend between all units was the fact that all units were offered both as an online course and in person through lecturers and practical sessions. This meant that students studying online could potentially have never studied in an online environment before. In addition to this, the method of introducing students to the laboratory involved having the students invited to access the laboratory by the lecturer of the subject, with the lecturer briefly going over the functionality the laboratory provided to students. At this point the online instruction manual on how to access the laboratory was posted in the unit’s online resources section in order to inform those students studying remotely. At this point both the remote students and those studying online had the resources required to access the remote laboratory.

5.3.2. Gathering Survey Responses

The survey needed to be easy for students to access, while still allowing for data to be easily gathered and analysed. Although the option to create physical
surveys was analysed, the ethics approval specified all results would be stored on a server located at Deakin, and therefore it was decided that an online survey tool would be utilised. Once the surveying tool had been determined, a set of questions needed to be developed in order to assess the way that the students learnt in the laboratory, what degree of realism they felt and also what they believed the learning objective of the laboratory was.

It was required to circulate an email in order to access the survey. The script for this email was required for ethics approval, and is given in the appendix 1 – section 12.1.2.

Along with this method, students were also provided a link on their subject’s home page with a link to the survey (and all ethics approved material). They were informed of the survey by email and from their class lecturer.

After the survey questionnaire had been granted ethics approval, it was then developed into an online web accessible survey. The software chosen for this was Survey Monkey. There were multiple factors that influenced this decision, such as ease of use, availability for the students, cost and ethical requirements. Survey monkey has the ability to remove all identifiable information from the students once they submit their survey, meaning that specific students cannot be identified based off of any identifiable information in the survey. This assisted with the requirement that all results must be completely anonymous.

Another advantage to survey monkey was that it was available on both mobile platforms as well as computer platforms. The remote laboratory was developed such that students were not required to access the laboratory from a
laptop or desktop computer. Due to this, students would be able to access the laboratory from a tablet, or more importantly a mobile device. Due to this, it was decided to set up the survey with a program or software suite that would allow students to access it from the same device they accessed the remote laboratory, therefore making it significantly simpler process for students to access the remote laboratory and then access the survey without needing to use multiple devices.

Survey monkey also includes the advantage in that it has the functionality to securely store all data gathered from the research participants via cloud storage. Securely stored research data being an ethics requirement made having this feature inbuilt into the survey beneficial. While it would be possible to implement this functionality in house, it would have taken extra development time which was not required if using survey monkey.

Having all responses automatically sorted into their relevant sections also made analysis much easier, as written responses for a single question were all presented in a single location, while responses to a Likert scale style question would all be automatically sorted onto a single bar graph so that trends could be analysed as they emerged.

The data collected automatically is formatted to display data trends, which makes analysis easier, however responses from a Likert scale must to be compared together. To accomplish this, the number of responses on a Likert scale will be weighted to produce a weighted average for each response. This weighted average will then be used to further compare data. This method is further
expanded in the second results section, focusing on the students’ perceived learning objective.

All survey results were hosted on the survey monkey servers, meaning that it was only accessible with the correct login information. This also added a layer of security to the data, as survey results were never collected on paper, meaning that both on paper surveys could not become misplaced or viewed by someone outside the project, but also that all data was hosted off site. Another advantage to having all data stored electronically is that all identifiable information was automatically removed, meaning that this additional step was not required to be completed by the researcher.

5.3.2.1. Analysing data from Survey results

Data from the survey was primarily in two formats. Either response to a likert scale, or as written responses. The written responses were analysed by grouping similar responses together and analysing the percentage of responses that fit into each category. These questions were generally looking for opinions on laboratory specific data, such as what they thought could be improved, or what students believed the primary learning objective of the laboratory was. This data was presented as a pie chart showing the weight of each response.

For the likert scale responses, a method of comparing each likert scale together was required. To do this, each related likert scale was required to be converted to a single numerical value. In order to achieve this, responses were given a weighted number, 0 for strongly disagree and 4 for strongly agree. This value was multiplied by the total number of student responses in that category.
With these numbers, the average weighted response of a specific likert scale was found. Comparison of questions answered via a likert scale response used this weighted number. Individual likert scales were either presented in bad graphs or via tables. Comparisons were presented using pie charts as a method of having all responses in a single figure.

A potential future improvement to this method is to present all perceived learning objectives on a single likert scale and have research participants select the single response they felt was the most appropriate.

Confidence interval calculations for these figures were handled by the standard error of the mean calculation (SEM). The calculation for SEM is done by first calculating the standard deviation of the data being presented, and then dividing this calculated standard deviation by the square root of the total sample size. This can be described by the below equation:

$$SEM = \frac{s}{\sqrt{n}}$$

Where SEM = standard error of the mean

s = sample standard deviation

n = sample size

5.4. Gathering user behaviour data

Another research topic that needed to be established was the methods in which students accessed the laboratory. For this research topic, that included
tools that were able to address access time, access devices and the number of
times accessing the laboratory.

Since the web interface of the laboratory was primarily programmed in html
and JavaScript, it was possible to include Google analytics into the web page
design. This software had advantages that will be discussed below:

5.4.1. Google analytics

Google analytics presents a method of observing the behaviour of users on
a website by using cookies. It automatically tracks this information and presents
it in easily analysed formats. While other alternatives with this functionality exist,
it was ultimately decided to use Google analytics in order to track the students’
behaviour while they completed the laboratory. The advantages of selecting
Google analytics will be discussed below, including the functionality Google
analytics provides to the laboratory, and what information Google analytics is able
to track.

5.4.1.1. Benefits of Google analytics

The benefit of implementing a system such as Google analytics is the
amount of information it can automatically track about the users accessing the
laboratory. While this information is all anonymous, it still gives an insight into the
behaviour of the users interacting with the laboratory.

An example of the information tracked is the user’s operating system and
web browser. This information is important when each web browser has its own
strengths and weakness in terms of how they can present information to the end
user. If the most popular web browser is known, this can be used to influence
design choices of later iterations of this laboratory. In the same sense, knowing the operating system of the users assists in ensuring the access modes they have available will be sufficient, as well as if any operating system specific tools will be required. Finally, in terms of access devices from the users of the laboratory, Google analytics can track the access device used, meaning if all users are interacting with the laboratory via mobile devices, the interface should be updated to reflect this.

In terms of user interaction with the laboratory, Google analytics has the ability to track the exact number of users per day. This means that user activity throughout the entire study period can be analysed. This information is presented along a timeline. The statistics collected also include new user’s verses returning users. This information is helpful in knowing how many of the students access the remote laboratory multiple times in their study periods. It will also keep track of users accessing only the first page (home page) verses those that view multiple different pages. In terms of the remote laboratory, this indicates users that are viewing static renewable energy data such as the logged solar energy generated in the last two hours, or the daily summaries of the logged data.

The information collected by Google analytics assists in knowing the activities and access devices of users accessing the laboratory. While it is important to know of the advantages of the system, it is not without its disadvantages. These disadvantages will also be discussed to ensure that they are understood, and that the design choices of the laboratory should be updated to
reflect the required changes in order to minimise these potential issues with Google analytics.

5.4.1.2. Shortcomings of Google analytics

This section will contain a brief discussion of potential shortcomings of using Google analytics to track user behaviour in the laboratory. It will cover two main areas, those being time spent accessing the laboratory and speed of data collection.

An issue with Google analytics is its ability to track users’ time spent accessing a web page. For this method to accurately track a user’s behaviour, they must actively move through multiple pages, meaning that if a user only visits or views the home page, their recorded time accessing the laboratory will be zero minutes. This presents an issue with the pages of the laboratory that update live, and therefore it was decided to include all live updates on the home page. Hopefully by encouraging people to view this data and then move on to the static pages, the data of time accessed will be more accurate.

The other potential issue with Google analytics is the speed in which it gathers data. It is very possible for Google analytics to report users’ behaviour hours after it has occurred. What this meant for the research project was that all user activity analysed must happen hours after users have stopped using the laboratory. What this meant was that analysis had to occur at minimum a day after students had finished their practical sessions. This was done to ensure that all data collected was available at the time of analysis.
5.4.1.3. Implementing Google analytics

The implementation of Google analytics was a relatively straightforward process. Collection of data was handled within the HTML web page, while the analysis steps were handled on the Google analytics web page.

After creating an account, an HTML script is created that can be copied into the website that tracking will occur on. For this project that was every page students had access to on the server. Once this script had been implemented, tracking was automatically done. The exact code used for this application is visible in appendix 3 – section 14.3.1.

In terms of receiving data, all tracked information was automatically recorded, and was viewable from the Google analytics web page. This data was automatically compiled into easily analysed formats such as bar and pie charts, and was also securely stored. This secure storage of data was an important step in the ethics requirements for this laboratory.

5.4.1.4. Analysing data from Google analytics

The data collected from Google analytics is automatically formatted into pie charts, which show an easy comparison of the current data trends. It also displays data such as number of students accessing the laboratory on a specific day on a single axis. Data such as this is also scalable, so exact time frames can be analysed, such as students accessing data during the entirety of the semester.

The use of pie charts offer the advantage of already displaying data trends, and comparisons between multiple different variables, for example the operating system used by students accessing the laboratory. This information is also
presented by simply the displaying the exact numerical data, which will be used for direct comparisons.
6. On campus students’ willingness to adopt remote education

Preliminary study

6.1. Publications
Sections of this chapter were published in the DesTech 2016 conference, titled 'Digital Laboratory Experiences: Creating Videos for Undergraduate Engineering Practical Sessions'

6.2. Introduction
Electronics practical sessions for first year engineering students are often used as a way to demonstrate basic information such as how circuits operate and to gain hands on practical skills. Analysis on student engagement levels in different delivery methods has been undertaken (Horan, Joordens et al. 2013) with results indicating preference on either system depending on factors such as the students’ chosen engineering discipline.

Within a project oriented approach to learning, the specific requirements for students change, and the delivery of educational content must therefore adapt to the changing educational landscape. Students are also showing they are willing to learn content through technology enabled learning practices (Joordens, Chandran et al. 2012). In recent years, the School of Engineering faculty has transitioned the in person electronics practical sessions to the Lab-Volt Fault Assisted Circuits for Electronics Training (FACET) board equipment (Lab-Volt Systems 2013) and its associated Mind-Sight software.
This allows for a more structured approach to students’ learning, but now with a shift of curriculum into project oriented design based learning (Chandrasekaran, Stojcevski et al. 2013), and having students’ perceptions be that design based learning will be beneficial (Chandrasekaran, Stojcevski et al. 2013, Chandrasekaran, Stojcevski et al. 2013) the structure of the laboratories must too change. With the addition of a remote laboratory to the teaching curriculum, it was decided to analyse students who primarily studied while on campus, and their willingness to learn in a remote environment.

Focusing on the first year electrical engineering subject, which primarily introduces basic electrical engineering information such as the basics of AC and DC circuits, as well as basic components, with a transition into two credit point, project based assessment tasks, the practical content delivery needed to be addressed as to not lag behind the new educational philosophy.

It was decided to film an instructor completing the practical sessions and allow students to remotely view practical content, while still being able to attend practical content in person. With internet speeds increasing, the use of video has become a dynamic learning tool that can be used to assist in the online engineering education process (Jackson, Quinn et al. 2013), and has been used previously to film lecture content (Al-Nashash and Gunn 2013) with positive results.

This chapter outlines background on the subjects’ practical delivery method, the method used to film practical sessions, and discusses possible future additions. The intention of this study is to analyse the willingness of primarily on
campus based students to adopt an education style that does not revolve around in person practical experience, instead relying on online resources to supplement or replace this in person experience.

6.3. Subject background

The unit that this section applies to is a first year electrical unit offered to students studying undergraduate engineering. The unit follows a project based learning philosophy and requires a large amount of group work on electrical projects for students.

To accommodate this, the unit proposed incorporating both online learning tools with the option of attending practical sessions, such that students would be able to watch pre-recorded videos of the practical sessions, but would also be able to attend the practical sessions as per usual in a more traditional setting, that being in a workshop with a lab instructor present. This gave students the electrical groundwork to be able to handle the project work required of them for this unit. It would also allow an opportunity to see if on campus students were willing to study in a remote environment, or if they preferred the remote study option.

6.4. Practical session overview

The practical sessions for this first year unit were run with the assistance of the Mind-Sight software and the Lab-Volt equipment and FACET board. The strength of this equipment is that it allows for a computer program to communicate with physical hardware to prompt users to take measurements and observations while walking them through the required steps and offering them extra information if incorrect attempts were made.
The topics covered in the practical sessions for students include both AC and DC circuit concepts as well as electrical safety, from DC circuits some topics included Ohm’s Law, series resistors, as well as phase angle and capacitive reactance from AC circuits. This was aimed to reflect the content covered in other areas of the subject, therefore allowing students to easily gain relevant information.

In previous years, often two or three practical sessions were completed in one sitting, allowing students to complete these sessions in a three hour block. However, the delivery method changed with the updated practical delivery session, allowing students to complete practical content in their own time. Starting week 2, between two and four videos were produced. More detail is presented in Table 2:

Table 2: Release schedule and total length of practical videos

<table>
<thead>
<tr>
<th>Study Week</th>
<th>Videos Released</th>
<th>Total time to watch all content (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3</td>
<td>51</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>48</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>82</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>45</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>88</td>
</tr>
</tbody>
</table>
6.5. Student access to practical content

The method used to allow student access to the laboratory involved posting video files online in order to give all students, those studying on campus and remotely, access to all content at all times. This differs from previous years where for the practical content, remote students were required to attend a full day to do practical sessions. Now that they can view the content online, this day is instead utilised for other work, such as project work with their team, having access to all required university facilities.

It is still possible for students to attend practical sessions if that is what they require to learn, or if they want hands on experience with the equipment before completing their project work for the class. Both methods were made available to the students. Since videos were made available week 2 of the teaching period, this was the time that students were able to attend the practical teaching sessions.

6.6. Recording the sessions

Each practical session was filmed over roughly an hour per practical, with each video being refined to last between ten and forty minutes. Camtasia Studio was selected as a video editing software as well as for screen capture. Practical sessions needed to be able to observe the Mind-Sight software program, as well as view any physical hardware being completed. Due to this, multiple cameras, a desktop microphone and a computer capable of screen capture were required in addition to the Mind-Sight software and hardware requirements for the practical session.
6.6.1. Camera Setup

Setting up the camera was done with the idea of having three separate viewpoints. One being a screen capture to allow students to read the instructions presented by the Mind-Sight software and to view any calculations being completed with an on-screen calculator, the second view was of the FACET board and any cable/measuring equipment required for that shot, such as multi-meters and two-post connectors. This was handled with a camera mounted above the board looking directly down. The third view was only used in required practical session videos, and was of the function generator and oscilloscope if it was used for that practical session. A single camera was set up to show these two devices, and therefore the instructor was required to pan the camera either left or right to be able to view this equipment. The process having the instructor move the camera was taken out of the final video to save time, however some of the panning motion was kept in the video to establish the position of the equipment.

![View of FACET board during practical video](image)

*Figure 5: View of FACET board during practical video*
The above figures, Figure 5 and Figure 6, show the outputs of the two cameras used in the filming process. The camera used to capture Figure 6 was also able to view a function generator which was sitting to the left of the oscilloscope. Figure 7 shows the screen capture, with the calculator being used as required. During normal operation the calculator was not open, allowing for all text and diagrams to be visible.

Figure 6: View of oscilloscope during practical video

Figure 7: View of software and calculator used for practical video
6.6.2. Editing

Editing the videos was done in Camtasia Studio. While it would have been possible to use other software, Camtasia Studio also allowed for screen capture to assist in recording the practical session, it was decided that this would be the best solution.

6.7. Student behaviour with extra content

An interesting outcome of presenting students with practical sessions in a video format is the subsequent drop in attendance to in person sessions. During the very first week of practical sessions a single student came to gain hands on experience with the lab equipment, however since that time attendance has not exceeded one student.

This could be due to the way the subject is structured, with assessment being project based, so students are using the videos to learn knowledge specific to the challenges they face in their project work. It will be important (and a requirement in future years) to ensure competency in electrical components, and while students are not attending the formal practical sessions, by being able to complete the other assessment tasks for this unit they will be required to prove this competency.

What it did show was students’ willingness to learn material presented to them in an online manner. The practical videos were presented to students weekly, with the number of practical sessions they would have completed being given to them.
The drop in attendance is likely due to students preferring to study in their own time, and without needed to attend the practical session. The space was made available for students who had the option of confirming their knowledge on the physical equipment, however students chose not to take up this opportunity.

6.8. Discussion

This chapter has outlined how practical sessions were filmed and presented to students studying undergraduate engineering. A total of 14 videos were recorded and presented to the students, which led to a significant drop in attendance to the in person laboratory sessions made available to the students. Students are still required to show competencies in their electrical engineering skills however. This shows a willingness for on campus students to engage in a remote style of education.

An interesting future study will be the abilities of these students as they progress through their undergraduate degrees. Allowing students to focus their skills solely on project work while supplementing these skills with video content of foundation knowledge allows for much more efficient presentation of content.

6.9. Conclusion

The purpose of this study was to ensure students were willing to engage in a remote style of education, and when given the option, nearly all students were willing to follow this educational method. This is important to know, as it shows a willingness to adopt this style of education, and as the laboratory analysed in this study was given to students as supplementary information, it needed to be established that students would be willing to engage in this new educational style.
7. Results – Students’ Engagement of Real World Remote Laboratory

7.1. Publications

Sections of this chapter were published in the AAEE2015 conference, titled 'NEW: Novel Design of a Renewable Energy Remote Laboratory'.

7.2. Introduction

When looking at the requirements of students completing undergraduate engineering degrees, the flexibility of learning is becoming an important metric to use. Engineering students have been shown to prefer a laboratory experience that allows them to approach their laboratory studies in their own time (Lindsay, Liu et al. 2007), and recognising tools such as the remote laboratory allows for the implementation of this learning flexibility as it ensures engineering students can access their laboratory content at any given time (Sousa, Alves et al. 2010). This enables those engineering students to organise timing of outside commitments such as work to complement their university studies. Remote laboratories as a tool can often be utilised to replace, or complement existing laboratories (Cooper and Ferreira 2009), as their differences from normal practical sessions (Feisel and Rosa 2005) opens new possibilities for teaching practical engineering elements.

Analysing the ways students approach learning on remote laboratories is an important step. While it has been established that students will approach their laboratories differently with different learning mediums, and therefore the method of interacting with students can be different (Corter, Nickerson et al.}
By having the laboratory open at all hours of the day, without the need for an instructor, the laboratory equipment can be available to students for a significantly longer period of time (Lowe and Orou 2012). This also opens up opportunities for laboratories to be available to students for longer time periods, accessing from any location, as the laboratory hardware could theoretically be available during the entire study period instead of when an instructor is available for that individual practical session. This also opens up opportunities for teamwork with individual students located across the globe (Yazidi, Henao et al. 2011). An advantage of this access mode is that it allows for laboratory equipment to be shared between universities (Lowe, Machet et al. 2012) or institutions (Lowe, Conlon et al. 2011) while not being used by the host university. This is due to the fact that not all laboratory equipment will be used by the host university for a constant time period.

As mentioned previously, remote laboratories are often separated into one of two categories, those being batch or active laboratories (Lowe, Murray et al. 2009). Batch laboratories are controlled by a user inputting set parameters into the experiment and then allowing for the experiment apparatus to automatically complete and then return the results of the experiment, either having the student download a logged file created previously or having the student return at a later time to collect the generated data. They type of data being generated largely determines the method of control given to the user, understandably not all remote laboratories should be set up to be batch or interactive, as this depends on the specific laboratory. For instance, this laboratory allowed students to interact with the laboratory by viewing renewable energy at specific times of the
day, however physical interactivity with the laboratory was not required. In addition, long term studies of solar power generated were possible due to this laboratory, with students not required to be present for these logging hours, due to this a primarily batch type laboratory was created.

This section will cover the novel approach to the design of the remote laboratory allowing students to view live data being generated by an active renewable energy system, as well as gain access to the logged data generated. The laboratory functioned by acting as a bridge between the Deakin University logging equipment and the inverter of the renewable energy systems. The data generated is presented to students and accessed through the Deakin University VPN.

With a system such as this in place, it is possible to show students the real world data for the expected inputs of a renewable energy system. The laboratory therefore allows students to covert the joules generated to watts, and to design a renewable energy system that would be capable of powering a specific system from the power generated by the outputs of the renewable energy system.

After this has been completed, an analysis of students’ access of the remote laboratory will be undertaken, focusing on access device, operating systems used and access times.

7.3. Challenges of the remote laboratory

In terms of remote laboratories, there are general requirements that need to be solved before the system can be brought online. It is possible to download remote laboratory frameworks such as the SAHARA LABS program (Lowe, Machet et al. 2012), or to create the server architecture in house. There are benefits to
both systems, especially systems such as SAHARA, as it has inbuilt error logging, student queue system, client-server architecture separated into a web interface, rig client etc, and other remote laboratory features that would not need to be developed by the designer of the laboratory. However, creating all laboratory architecture allowed for a much greater degree of control over all aspects of the system, and for a simpler lab layout, it does not require all of the features that SAHARA LABS supplies.

When creating any remote laboratory, specific challenges must first be addressed. A brief overview of some of these challenges is below:

For the remote laboratory to be accessible to students, the required hardware needed to be accessible to students from many different locations, and using multiple different hardware solutions. This generates a unique problem for the design, as a system homogenous solution needed to be created. In addition to this, accessing the remote laboratory becomes an issue when you consider that the laboratory is able to be run at all times of the day, even if solar power is not being generated during the low light hours.

The remote laboratory needed to be set up such that minimal installation files were required for the end user. Ideally they would be able to log onto the internet from any computer and easily be able to access the remote laboratory through a web page. In addition to this, accessing the remote laboratory through multiple different web browsers and even mobile platforms becomes a benefit.

Once these issues have been addressed, issues with creating the specific remote laboratory to gather the data from the renewable energy system needed
to be addressed. An important criterion of this remote laboratory is that it was able to interact with a real world working system. The solar panels and inverter were logging data for other projects, and therefore any hardware needed to be able to interact with these systems without interrupting any of the data transmissions. It therefore needed to be able to interact with any data being transmitted, not interfere with this data and still run scripts to gather data for the remote laboratory.

7.4. Remote Laboratory Design

The overall server architecture could be split into two sections, those being inverter communication architecture and server side architecture. By design, the inverter architecture dealt with all data collection, while the server side architecture received all data and converted it into a format that the students were able to access.

The server side architecture was primarily programmed in python, with all web interface programmed in lamp 14.04 (Linux, apache, MySQL, PHP).

The inverter communication architecture was handled with a raspberry pi communicating with the inverter and Deakin University monitoring hardware via the RS232 connection between the two devices. A brief overview of the system is shown in Figure 8.
Figure 8: Shows a brief overview of the remote laboratory structure

7.4.1. Inverter communication architecture

The hardware for the rig client of the remote laboratory involved using a raspberry pi to enable communication between the already established hardware systems. In an attempt to allow communication to the inverter, the RS232 logic converter was disconnected and connected to the raspberry pi (both plugs were converted to USB input for this step). This is shown in Figure 9.
The raspberry pi was selected due to its ease of programming, as it was essentially a simple yet effective Linux device. It allowed for remote access and control from the server which was also using a Linux environment, meaning that any small changes required could be done remotely, and programming the device could also be done remotely. Although possible to establish communication with something such as the Arduino platform, the raspberry pi had all required hardware outputs such as multiple USB ports, an Ethernet input and could be used to easily program in python. The pi could also be set up to automatically run the required python scripts, so in the event of a power reset, establishing communication between the raspberry pi and the server, as well as communication between Deakin University’s logging hardware and the inverter.
can all be set up to happen automatically, meaning that server downtime in the event of a restart is minimal.

Since both RS232 connections were converted to USB outputs and connected to the raspberry pi, it was required to set up the raspberry pi to allow automatic communication between the two USB ports. With this system in place, the Raspberry Pi was therefore able to wait for a break in communication and send its own commands to the inverter. Since a single inverter is used to handle both the solar panel and wind turbine output, only one raspberry pi was required.

The data collected from the inverter was the joules generated in the last ten seconds, therefore the raspberry pi only needed to take one reading every ten seconds to be able to gather all required data from the inverter.

Figure 10: Shows the connection between the inverter and Deakin University logging data that the Raspberry Pi intercepted
Figure 11: Shows the inverter used to gather solar data

The method of controlling the pi used threading, having one thread responsible for communicating with Deakin University logging equipment, one thread responsible for communicating with the inverter, and the final thread controlling logging data once communication is allowed. Using threading is advantageous as it allows for all three threads to be executed simultaneously. The exact code to achieve this is viewable in appendix 3 – section 14.1.2.
While Figure 12 shows the communication of the code, the exact flow of information between the solar inverter, the web server and the pre-existing logging hardware, it does not show the exact flow of information. This is better portrayed in Figure 13.

**Figure 12: Shows the communication overview of the Raspberry Pi**

<table>
<thead>
<tr>
<th>Thread 1</th>
<th>Thread 2</th>
<th>Thread 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receive bit from inverter</td>
<td>Wait for break in data sending</td>
<td>Receive bit Logging hardware</td>
</tr>
<tr>
<td>Send bit to Logging hardware</td>
<td>Poll inverter for Joules generated</td>
<td>Send bit to inverter</td>
</tr>
<tr>
<td>Send data to server</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
7.4.2. Server Side Architecture

The server side architecture was developed in a way that involve splitting all behaviours into two sections, the required program to communicate with the Raspberry Pi, and the programming to create the web interface to correctly communicate with students completing the remote laboratory.

To communicate with the Raspberry Pi, a UDP protocol was used. Data received from the raspberry pi was automatically stored in a MySQL database. The server side was responsible for all analysis of data, meaning it would also input the time logged into the database. This led to an issue with the data being logged, in that the data stored would be logged at roughly 2-3 seconds after it was initially read by the Raspberry Pi, however since the data was the joules generated over ten seconds, this delay was considered acceptable. An overview of this
communication between the logging hardware and the server is presented in Figure 14.

Figure 14: Overview of communication between logging hardware and web server

Once the data generated from the Raspberry Pi was being properly stored, it then became important to generate a web page that would properly be able to give this information to students attempting to access the laboratory. For this, LAMPS (LINUX APACHE MYSQL PHP) 14.04 was used. LAMPS is a set of open source software packages that allows for the creation of web pages that communicate with data stored in the database.

The advantage of using LAMPS is that is allowed for coding web pages in HTML and PHP, therefore most web browsers would be able to access and operate in the page.

Since the web page was hosted using one of Deakin University’s desktop computers as a server, it requires logging into the Deakin University VPN. This is
easily done using JUNOS PULSE, with the Deakin University website hosting instructions on how to properly set up and access the VPN. This allows students to easily access the web server.

When students access the web server, they are given the option of viewing data as it is generated live, such that a graph will be created updating the data points as they are read from the solar inverter in real time, or by viewing the last two hours of data generated on a static graph.

The graph showing live data is set up such that it will poll the MySQL database every ten seconds to access the last stored data point. This data point is added then added to the graph, updating on the students’ web browser. This method allows the student to see the live data output, and to get a better understanding of the erratic nature of renewable energy power outputs. The code required to achieve this is viewable in appendix 3 – section 14.2.1 and section 14.2.2.

The web page also links to CSV files for the students to access logged data from the inverter. This allows students to do analysis of the data over a much longer period of time, not only while they are physically viewing the data generated.

The CSV file contains the data logged as well as the time logged, the date and the ID number of the data logged.
An example of the expected output for the solar inverter is shown below. The data was taken at mid-day, and shows roughly 30k joules being generated every 10 seconds.

![CSV file of solar data](image)

*Figure 15: Shows the output CSV file of solar data generated by the remote laboratory*

### 7.4.3. Web layout

When a student logs on to the web server, they are immediately shown a graph with the live data being displayed. An example of this is the graph shown below. Note, this graph is the result of two minutes of logging data.
Figure 16: Shows the output graph of live data being generated, measured in joules

While this graph is informative, if a student is looking to quickly see a large amount of data, it is possible to show the last two hours of data. This is presented to the students as shown in the following figure:
While it would be possible to wait for two hours data to be logged to see the same graph, students can instead log in and immediately see the last two hours’ worth of data. This allows for the user to see recent trends with the data output. The above data, for example, was taken at 7.30PM, showing the large drop off of output joules. There was a bug for the first cohort of students where the x-axis did not show time, but instead the number of data points collected. This was quickly fixed, with the updated graph being shown in Figure 18. The y axis was also updated so that instead of showing the output in joules it expressed the output in watts.

Figure 17: Shows the output graph of two hours’ worth of data, measured in joules.
Figure 18: Shows the output graph of two hours’ worth of data with fixed x axis, measured in Watts

If the students wish to see a larger amount of data, they will be required to access the log files. This involves downloading the CSV file for a specific data range, and manually graphing the data.

An extra feature of this laboratory is that while connected to the Deakin University wireless network on mobile devices, the lab can be accessed in much the same way. A screenshot of the lab while accessed from a mobile device is shown in the following figure:
Figure 19: Shows the mobile device interface for this remote laboratory

While the above figure may be hard to view, it is possible to use the zoom function on the mobile device to zoom into interesting parts of the graph to allow for a much easier viewing experience for the end user. An example of a zoomed view is shown below. Note that reading exact values from the graph is now made significantly easier.
Figure 20: Shows the zoomed in interface for mobile devices

By allowing the students to access the remote laboratory from a mobile device, the usability of the lab increases significantly.

The server therefore was able to communicate with specific databases as well as handle student queries for specific information. A summary of this process is presented in Figure 21.
7.4.4. Limitations of this design

In this section, two of the core limitations of the laboratory will be addressed, those being the static nature of this laboratory, and the region of error of the readings. As with any laboratories, it is important to note these limitations.

7.4.4.1. Static nature of the laboratory

Many of the remote laboratories observed in the literature involve having moving parts, or parts displaying specific principals through motion. This movement can be demonstrated in laboratories discussed previously, including the projectile motion laboratory and the bending bar remote laboratory. These laboratories are able to use moving parts as the concepts they are displaying allows for this movement. When dealing with electrical concepts, which require showing electrical inputs and outputs, this can be a harder subject to visually display.

Possible solutions were discussed for this, however were not implemented. One of those solutions involved utilising a web camera to show the sky, displaying
change in weather and having this change link to the changing outputs of the solar inverter. Another discussed method was to focus on wind energy and to have the movement of the wind turbine displayed to the students again via a web camera. Both of these solutions allow for the student to see moving, or changing inputs in a renewable energy system and correlate this with the changing outputs. It was chosen not to implement these changes as it was felt that the graphical information presented to students would suffice, however future iterations of this laboratory may include them. The graphical information presented to the students will still update in real time as the physical hardware is changed, mathematically showing the change instead of relying on moving equipment.

It is believed that this research is not limited by the lack of moving elements, as with electrical systems, it must be understood that specific concepts may not be immediately visible to the human eye. This does not mean that the idea of a moving element in the experiment has not been considered, and future iterations may incorporate moving elements.

### 7.4.4.2. Region of error

Another limitation that needs to be addressed is the region of error presented in the measuring equipment. This error in measuring equipment effects three very important sections of the laboratory.

When determining the joules generated, the reading of the inverter can be out by as far as 2%. At its maximum reading of 3kJ, this demonstrates an error of ±60 Joules. This error is also compounded by the fact that daily logs are created with the measurements and presented to the students. These generated log files
display the measured daily energy generated, and can have an error of up to 4% (Power-One 2009).

The last region of error to be discussed is the time calculation. When converting the energy generated to watts, the time it took to generate the specific number of joules must be known. This time is set at ten seconds, however can have errors of up to 0.2 seconds. At the maximum energy generated, 3,000 Joules, this would be 300 watts, however due to the ± 0.2 second, could have a reading of 294.12 watts to 306.12 watts, a range slightly larger than 11 watts. This error can also be increased by the error of the initial joules reading (Power-One 2009).

While having an error in a measurement is not ideal, when dealing with physical equipment and not computer simulations, it is something that must be expected. As this error is consistent across all readings it is not expected to significantly impact results.

7.5. Students accessing the laboratory

This section will cover the methods used to allow students to access the laboratory, however first a brief discussion on the students accessing the laboratory is required. The laboratory was set up to enable a class of students’ access to the laboratory in order to view live outputs of a renewable energy system. This was in order to aid them in gaining a better understanding of the outputs to grant them a better understanding of such a system before allowing the students to work in groups to design and simulate their own renewable energy system.
Students in the class were both studying in on campus mode and remotely. All students needed access to the same resources, so remote access to any practical material needed to be considered. While it would have been possible to have a computer logging all of this data be accessible by the on campus laboratory computers, this led to issues with off campus students, who cannot be expected to attend an on campus day in order to see outputs of a solar panel, and even if they are, it only shows a small snapshot of the behaviour over a small period of time, instead of over the extended period of time a logging system such as the one presented in this paper was designed to allow.

In addition to this, students needed to be able to access the laboratory from multiple different locations. Since tutorials were not held in a computer laboratory, software could not be installed on the user’s computer, and it was not possible to assume that students would have the correct software installed to view the data.

The units being studied was also run such that there was no specific requirement on hardware/software usage for this class, meaning that any material needs to be accessible from a wide range of devices and operating systems. The unit being studied also had no specific hardware requirement for access devices, which meant that all server side architecture needed to be accessible from any device using a web page (it was decided early on in the development process not to have something installed on the user’s computer).

These issues resulted in requiring an architecture that was accessible from multiple different devices, all with different screen sizes, all using potentially
different software and operating systems. While this may seem like a large task, it is becoming a reality that students now expect a university degree to accommodate their lifestyle, and laboratory access is currently being affected by this, with students expecting a laboratory to work with their own devices, and as such laboratories must be built in this manner. Making sure students could access the laboratory in an easy manner was also an important requirement of the laboratory.

7.5.1. Student devices used to access laboratory

A survey was completed with undergraduate engineers looking at what devices they used to access online content to support their learning, with Figure 22 showing the percentage of students using specific devices (numbers add up to greater than 100% as students were instructed to tick all that apply). What is interesting about this data is that there are more students using apple devices (IPad and IPhone), yet software can often be written to be compatible with non macOS devices in mind. It was decided with these results in mind to ensure a server that is accessible from apple devices, as well as windows and android devices.
After it was established that most students use apple devices when accessing material on-line, however this was focusing on mobile devices. When looking at specific operating systems and web browsers selected, it can be seen that not only is this trend (more Macintosh products such as apple branded computers) holds true. In Figure 23 it can be observed that the majority of users at 49 percent used the Macintosh operating system. This is higher than windows users, with only 38 percent of users accessing the laboratory on windows devices.
When looking at the web browsers used to access the laboratory, Google chrome was the most popular accessing browser according to the collected results, with over half the users opting to access with this browser. Firefox and Safari web browsers were observed to be the second and third most used web browsers respectively. This is an important metric to know, as some web browsers work better with different plug-ins and applications (flash player being a good example), and knowing the preferred operating system is Google chrome is a design consideration that could become important in future iterations of this laboratory. The browser selected is shown below in Figure 24.

Figure 23: Operating system used by students accessing remote laboratory
7.5.2. Student access over time

When looking at the access time of students, a large number of users accessing the laboratory can be seen on 15th of July, and then again a week after this. This corresponds to the time the students were first given notice of the laboratory, and then a week later where they were reminded of the laboratory and its functionality. This access trend is displayed in Figure 25.

The two large access spikes initially, followed by relatively low access numbers. This is to be expected however, as after students have observed the data, it was not expected to have return views unless they are using the log files for their projects.

Figure 24: Browser used by students to access remote laboratory

Figure 25: Student activity over time (12/07/2016 – 12/08/2016).
Another metric observed is the number of unique users accessing the information presented in the laboratory. Figure 7 shows that of all those accessing the laboratory, 73 percent were new visitors with 27 percent of people returning. While this does show a low number of people accessing the laboratory multiple times, it was found that users accessing the laboratory viewed on average 2.63 pages, showing that they observed more than simply the home page, which gave students access to all live data. This data is shown in Figure 26.

![Figure 26: New and Returning visitors of the remote laboratory](image)

While students on average accessed 2.63 unique pages, it was observed that 63 percent of users only accessed the home page, which gave them access to the live output of data, but also indicated that they did not look at the supplementary information such as logged data.

7.6. Discussion

This section covers the results of setting up the remote laboratory as well as the methods students used to access the laboratory. With the idea of creating a
server able to handle multiple different access types, the LAMPS package enables the server to run dynamic web pages without the need to have extra software installed, and also enabled a MySQL database to be used not only to store all data, but to be used in order to set flags high, and to therefore communicate with the raspberry pi. Each component of this laboratory design needed to be able to communicate with the other, and to effectively manage data flow between themselves. This laboratory also was required to function as part of a larger system (that being the solar inverter) in a way that did not interrupt the data gathering from that system. A nice addition to this laboratory is that it was designed in such a way that all devices, operating systems were able to access the laboratory without needing additional software installed.

The strength of this layout is that it allowed the end user to view all data in the database from an html page, with PHP handling all requests to the database. This was set up in such a way that all data was securely stored, and that the database was not accessed directly by the student, but instead only responded to scripts the student called, therefore removing the ability for the student to interfere with, and possibly modify the database logged data. This layout was selected as it easily allowed for a web server to be created that did all processing server side, therefore not requiring the user to do any processing, leading to more control over the exact content they had available, as well as control over the format this content was presented.

The raspberry pi was responsible for querying the solar inverter for the exact data being generated. This was then sent to the database using the User Datagram
Protocol (UDP) protocol, an alternate to the TCP/IP protocol. The database (or more specifically the computer the database is on), running Linux, then receives the data, formats it into a usable format, timestamps the data and stores it in the database. The joules generated over the last ten seconds is what is received, and therefore at this stage the watts generated over this time is determined, and this is also stored.

What this means is that every ten seconds a data point is generated, leading to a new row in the database being generated, containing a specific row ID, joules and watts generated over the last ten seconds and the year, month, day minute hour and second this data was generated.

The web server in this setup was required to allow multiple students to access the data at any given time. This meant that all data displayed had to be unique to the student viewing it, instead of as a static web page.

Html coding was required to provide an interface for students to access the laboratory. It allowed for a catch all access mode for students, with scripts running from PHP able to interface with the required databases. PHP was used in this case as it allowed for access of specific database information quickly and easily, with plenty of support available. Since this web server architecture was developed in house, a design needed to be developed that allowed for ease of programming, as debugging and implementation needed to easily and efficiently occur. Having a large amount of online support for html, PHP and general MySQL database design was essential for the completion of this laboratory.
One of the benefits of setting up a system such as this is that programming for specific operating systems or more importantly different devices is not required. Oftentimes creating a mobile interface is a requirement for students wishing to use a laboratory from a mobile device, however for this laboratory that is not the case. Due to mobile devices often containing pinch to zoom, and designing around the concept of having information shown in easy to access locations, a mobile device is adequate to see the information in this remote laboratory.

The design overview of the laboratory involved using updated database values to act as flags for interacting with other devices. The html page was able to view and stare values in a MySQL database, meaning that advance functionality could easily occur, with extra features being added at a later date if required.

Figure 23 shows a large portion of students accessing the laboratory used a Macintosh operating system. This would appear to be supported by the responses shown in Figure 22 which had a large portion of students on mobile devices favouring apple devices. As expected, window devices followed the mac devices, however with an 11% lower response. This number was taken from google analytics, showing over 158 unique sessions over the entire trimester study period, meaning that the 11% represents 17.4 less students accessing the website with a windows device. Linux devices, with an eleven percent access rate was the third most used operating system, with android appearing last, with only two percent of students accessing the laboratory using android devices.

The number of students using apple devices could be inflated, as it combines both iPhone and Mac computers into a single category, however the trend is still
towards devices with this operating system. Because of this, using remote laboratories that require flash applications, or other windows OS specific hardware would not be ideal, as it would make over half the students unable to access the laboratory content.

At this point it should be noted that while design considerations of this laboratory allowed the software to function on Macintosh devices, design considerations rarely incorporated methods that would favour a Macintosh style operating system. While functionality would likely have been similar if not identical, knowing that over fifty percent of users were using this operating system means that design considerations should take this into account.

In terms of browser selected by students, it was seen that 64% of students selected the Google chrome browser. Since 49% of students were using Macintosh, by far the most selected operating system, what this means is that Google chrome was being used as the most popular web browser across multiple platforms.

Following this, the second most used browser was Mozilla Firefox. While Mozilla Firefox and Google chrome are both open source applications, the media codecs supported vary between the two.
Table 3: Different media codecs supported by Google chrome and Mozilla Firefox

(http://www.difffen.com/difference/Firefox_vs_Google_Chrome)

<table>
<thead>
<tr>
<th>Firefox</th>
<th>Chrome</th>
</tr>
</thead>
<tbody>
<tr>
<td>WebM</td>
<td>WebM</td>
</tr>
<tr>
<td>Ogg Theora Vorbis,</td>
<td>Vorbis</td>
</tr>
<tr>
<td>Ogg Opus</td>
<td>Theora</td>
</tr>
<tr>
<td>MPEG H.264 (AAC or MP3)</td>
<td>AAC</td>
</tr>
<tr>
<td>WAVE PCM</td>
<td>MP3</td>
</tr>
<tr>
<td></td>
<td>H.264</td>
</tr>
</tbody>
</table>

While not completely relevant since the large number of Macintosh devices used, the flash player is supported on both operating systems but only built into Google chrome, meaning Firefox users will be expected to install an extension.

Safari and internet explorer were the least used browsers, having a combined usage of seven percent, with internet explorer having the least users of the two.

What is important to note is that of the two most used browsers, not all media codecs are supported between the two, so any remote laboratories that require specific audio/video streaming need to consider this.

Looking at students accessing the laboratory, the number of students viewing the website was tracked using Google analytics. The timeline for this
tracking was 12\textsuperscript{th} of July 2016 until the 12 October 2016. As can be seen be Figure 25, there was a large spike of activity when they first were introduced to the resource. While this is unsurprising it quickly becomes apparent that students were accessing the laboratory only when being reminded of its existence by their lecturer. This can be seen by the first two spikes of students accessing the laboratory happening exactly a week apart, on the Thursday 14\textsuperscript{th} of July and then on the Thursday 21\textsuperscript{st} of July, exactly one week apart.

After this, the number of students accessing the laboratory dropped significantly until exactly a month later, on the 14\textsuperscript{th} of August, where a reminder email was sent to all students, containing a link to the online laboratory. Even with this increase in student attendances, it was only 8 students on the 14\textsuperscript{th} of August and 11 students on the 15\textsuperscript{th} (most likely due to checking their emails the day after the email was sent). This combined 19 students accessing the laboratory does not compare to the 29 accessing the laboratory initially. The large drop off from students was not unexpected, however there is still activity over the remaining duration of trimester.

New visitor verses returning visitor was also analysed, to see if students would access the laboratory multiple times. If was seen in Figure 26 that the number of returning visitors was 27\%, meaning a majority of students accessing the laboratory only viewed the laboratory content a single time.

This could be due to the fact that the material was not assessed, and so students instead only viewed the laboratory as a way to see the theories they had
been learning about represented by the laboratory system, and once this had been done, no longer saw a need to access the laboratory content.

7.6.1. Suggestions for future research

Currently, the remote laboratory is missing live outputs from the wind turbines. It would be possible to add these outputs to the graph in the same way as the solar data, however further testing to assure that the communication between Deakin’s logging hardware and the inverter is not disrupted would be first required.

Another add on that would be beneficial is the inclusion of a live feed from a web camera showing the solar panels. This would act as a reinforcement to prove to the students that the data is real, as well as having a visual indicator for the light levels compared to the solar output. The current design for a web camera is to stream a single image that updates every ten seconds as to not go through too much of the users’ bandwidth.

Currently there are plans to migrate the server from a location hosted at Deakin University to a server hosted in a different location. The reason behind this is to enable users to log in to the web server without requiring to connect to the Deakin University VPN, and mobile devices will be able to connect to the server while not connected to the Deakin University wireless network.

7.7. Conclusion

This section covered the design of a remote laboratory that allows students to see the outputs of a renewable energy system in real time from any location with an internet connection.
The purpose of this laboratory is to allow students to learn about renewable energy systems from equipment using real world inputs. It allows students to see live data being generated in real time, and to see the effects of changing light conditions on the outputs in real time. It also allows students to see data live, as it would actually be generated, instead of analysing data such as the daily average.

The fact that a remote laboratory such as this allows students to access this information at any time, even from their own home, allows the way that students approach education to change to allow a greater flexibility in their undergraduate engineering study.
8. Results – Students’ Perceived Learning Focus

8.1. Publications
Sections of this chapter were published in the AAEE2016 conference, titled 'Solar Energy Logging Laboratory'. Journal article covering this chapter submitted to the European Journal of Engineering Education (EJEE) titled 'Student Experience in Solar Energy Remote Laboratory' and is currently under review.

8.2. Introduction

Engineering education has evolved past the point of students being expected to sit in a classroom and learn from only lectures and tutorials. New styles of presenting information are being developed, such as remote laboratories, and therefore it is not enough to merely rely on older teaching styles and methods.

Remote education as an education medium has received scrutiny to ensure it is as beneficial as being physically present for education. Simulations and remote laboratories are often used in parallel with standard teaching methods (i.e. hands on laboratories). An issue with remote education is that the attrition rate of the students can be up to 10-20 percent higher than on campus units (Angelino, L.M., Natvig, D., Williams, F.K., 2007). Therefore methods of further engaging students in remote education should be continued along with the current studies that involve analysis of student feedback (Lindsay, E., Liu, D., Lowe, D., Murray, S., 2007).

When looking at personal perceptions of effectiveness between simulation and physical laboratories, 72 percent of students found the laboratory to be “about the same” as traditional laboratories (Corter et al, 2004) yet it has also
been found that students scored higher on reports written from a simulated laboratory compared to a physical laboratory (Balakrishnan and Woods, 2013). These findings are of interest when you consider the debate between Clark and Kozma (Clark, 1983, 1994 Kozma 1994, 2000), who looked to analyse if presenting information through a specific medium had educational benefits, or if it leads to any change whatsoever.

Students are also known to interact with different equipment in different ways. Students interacting with remote laboratories show a tendency for students to become engaged in self-directed learning (Böhne, Faltin et al. 2002, May, Terkowsky et al. 2013). While not a new concept, it is most certainly a requirement for distance education where the student must actively engage in learning the material without an instructor present. It has also been shown that in a remote laboratory, a student will approach the learning material with a different mindset than with other mediums (Lindsay and Good 2005). Lindsay and Good found that when focusing on students’ belief of objectives in a remote laboratory, it was found that 20 percent of students thought that the remote laboratory was about understanding the hardware, while only 6 percent of people undertaking the same practical whilst using a simulation believed this.

Remote education, including remote laboratories and simulated experiments, possess the ability to educate in ways that are not possible when using the standard laboratories (Cooper and Ferreira 2009). Due to the requirement of most simulations and remote laboratories to be completed by a student without an instructor present, a student must be able to interact with the medium in entirely
different ways, including hybrid labs that involve elements of remote, simulated and hands on laboratories (Abdulwahed and Nagy 2013). Comparing remote laboratories to simulations, students have a preference for being able to witness the experiment being completed, and having one trust in the authenticity of the results (Jona, Roque et al. 2011).

To add to this, when students perceive an experiment as being real, or using real equipment compared to being modelled in a simulated computer environment, they interact with the experiment differently (Sauter, Uttal et al. 2013). This interaction is important, as with proper understanding, the students’ focus could theoretically be manipulated into focusing their attention on a desired learning objective.

This chapter aims to present students with a remote laboratory showing outputs of a solar inverter, and to analyse their experiences in this laboratory.

8.3. Laboratory overview

The laboratory discussed in this paper was made available to students studying undergraduate engineering as well as postgraduate engineering. An example of one of the units it was introduced in aims to allow students to investigate renewable energy systems, and to allow them to gain exposure to the outputs of such a system. The unit required students to run a simulation of a renewable energy system for a chosen location accounting for factors such as changing lighting conditions throughout the entire year, as well as average wind speeds and other weather effects. Students therefore needed to have increased exposure to renewable energy systems in order to allow them to more accurately model their
own systems. Other units focused on processing the outputs of renewable energy systems, as well as addressing different renewable energy generation methods.

In an attempt to increase student exposure to solar energy systems, this remote laboratory was designed to show the outputs of a solar inverter located at the university. The remote laboratory was not a graded assessment for any of the units it was implemented in, and was instead given to students as an extra resource to allow them to view the inverter outputs. Since the laboratory was not assessed, it allowed students to view all outputs in their own time, taking however long they required.

The outputs of the laboratory allowed students to see the changing joules and watt output generated by the panels. This data was updated at ten second intervals. In addition to the live updates, it is also possible to see a snapshot of the last two and twenty-four hour periods. This allows students to quickly and easily see trends with the output power with respect to time of day. In addition to viewing the information, students can also download a CSV file that again shows the generated power at ten second intervals for the last 24 hours, or a log file of the daily averages and maximum power outputs over the past three years.

*Table 4: Example of outputted log file starting at 9.00AM on 26/02/2016*

<table>
<thead>
<tr>
<th>Id</th>
<th>Joules</th>
<th>Year</th>
<th>Month</th>
<th>Day</th>
<th>hour</th>
<th>minute</th>
<th>Second</th>
<th>watts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1407706</td>
<td>5416</td>
<td>2016</td>
<td>2</td>
<td>26</td>
<td>9</td>
<td>0</td>
<td>4</td>
<td>541.6</td>
</tr>
<tr>
<td>1407707</td>
<td>5387</td>
<td>2016</td>
<td>2</td>
<td>26</td>
<td>9</td>
<td>0</td>
<td>15</td>
<td>538.7</td>
</tr>
<tr>
<td>1407708</td>
<td>5360</td>
<td>2016</td>
<td>2</td>
<td>26</td>
<td>9</td>
<td>0</td>
<td>26</td>
<td>536.0</td>
</tr>
</tbody>
</table>
Table 4 displays the data generated by the short term logged file. Every entry has a unique Id, and shows the total amount of joules generated over the last ten seconds, as well as the year, month, day, hour, minute and second this data was generated. For ease of use, the logged output also shows students the value converted to watts. The server would receive and save this data to a database before displaying it to students. The code would also display to the user the data being stored for debugging purposes. The initialisation output is given in Figure 27.

![Start Initialization, database open
End Initialization
End of Part Acception
7610
761.0
8034
803.4](image)

*Figure 27: Initialisation code outputs*

The solar inverter gathered information on a ten second cycle, meaning that all joule information gathered was the amount of electrical energy over the last ten seconds. Creating a query for solar power generated more often than this would lead to the same numbers being returned.

As power (measured in watts) is calculated by energy (measured in joules) over time (measured in seconds), calculating the watts generated was a simple task of dividing the joules generated by the time period, in this case ten seconds.

Access to daily logs were also possible with this laboratory. These daily log files dated back to 2013 and were accessible through the menu of the laboratory. This page is shown in Figure 28.
Figure 28: Menu to access log files

Figure 29 shows the daily summary information. This was included to allow students to see long term trends for the power output. Instead of a data point every ten seconds, the file presents energy generated every ten minutes, as well as the daily total and lifetime energy generated for the system. The system on time and off time are also given, showing the operating hours of the system for every single day.

```
[system status]
Time: 30/03/2014 7:42:50 PM
System On Time: 30/03/2014 7:32:51 AM
System Off Time: 30/03/2014 7:42:50 PM
Today Energy: 14.9 kWh
Lifetime Energy: 5428.3 kWh
```

Figure 29: Outputted log file from 30/03/2014

The laboratory was available to students during the entirety of the unit. Its primary purpose was to give students exposure to the outputs of a solar inverter,
and to enforce the inverters behaviour, such as having zero power output during the night, and very unreliable outputs during cloudy days. The intention of this was to encourage students to look into or consider possible solutions to providing reliable power to a simulated environment, and to look at systems that would provide power at times that solar is unavailable.

The students were given information on how to access the laboratory in a news item posted on the subject page accessible by all students and teaching staff for the unit. To access the laboratory, students simply needed to open a specific URL and it would immediately take them to the laboratory.

8.4. Case study Outline

A case study was completed by students initially accessing the laboratory. This study used students already enrolled in a renewable energy undergraduate engineering second year unit. The subject is a requirement for completing both the electrical and electronics engineering major, and the mechatronic engineering majors.

The subject required groups of students to observe solar and wind outputs for a location in Australia from sources such as Bureau of Meteorology. They were then required to create a renewable energy system capable of providing enough renewable energy to either allow the location to live completely off grid, or to feed energy back into the grid. Students were required to analyse all renewable energy sources over the entire year and decide on the most beneficial way to implement their renewable energy system, as well as to answer questions such as
how many solar panels would be used in an array, what direction should they face and what percentage of energy can be made completely renewable.

Completing the laboratory consisted of students accessing the laboratory through the provided URL as well as the instructions shown in appendix 1 (12.1.1). Students were then given the chance to analyse the changing outputs, and to consider the implications of such a system in their own design. They could also access the long term log files to see the change in outputs of a renewable energy system at different times of the year.

At the completion of the unit, students were asked to fill out a survey of their experiences in the laboratory, focusing on their perceived learning objectives. This was similar to the study presented by Lindsay and Good (2005) which aimed amongst other things to analyse different perceptions of learning objectives between different educational mediums and access modes. The survey also allowed students to give general feedback on both the subject and the laboratory and to provide feedback on if they perceived the data and system to be simulated or real.

The survey consisted of 8 questions (appendix 1 – section 12.1.3) and took an estimated 10 minutes to complete. It was issued at the completion of the unit and open during the inter trimester break. Completion of the survey was completely voluntary. Student responses were anonymous and did not have implications over their final mark. A total of 34 students completed this survey. While this number was low, other avenues of collecting data were explored, such as using information from google analytics.
8.5. Student responses

The survey (appendix 1 – section 12.1.3) completed allowed for both the gathering of qualitative and quantitative data. By collecting student responses it was possible to look at both the way students were interacting with the laboratory as well as their opinions on the laboratory. An overview is given in Table 5, Table 6 and Table 7.

Table 5 shows the written responses to the survey question “What do you feel the primary learning objective of the remote laboratory was?” Answers from this question trended to one of two possibilities, those being either ‘real time visualisation of outputs’ or ‘power and PV cells’, with other responses being recorded in the misc/other category. The percentage of responses for each category, as well as example responses are given in Table 5.
Table 5: Sample of student responses from survey question 2

| What do you feel the primary learning objective of the remote laboratory was? |
|---|---|---|
| Response Trend | Example | Percentage of responses |
| Real time visualisation of outputs | “access to real practical results anywhere anytime” | 31.6% |
|  | “Visualisation in real time” | |
| Power and Photovoltaic cells | “To study the power output from the solar energy as the source” | 52.6% |
|  | “To analyse power generation characteristics” | |
| Misc/Other | “apply technical knowledge and the use of computer assisted applications” | 15.8% |
|  | “To receive live data for students that cannot make it to class/labs” | |

The following figure (Figure 30) shows this data in a graph to make the percentage values easier to visualise. It can be seen from this figure that over half the responses gained were regarding PV cells and power.

An important note is that a majority of the responses were regarding lab specific, with very few students giving responses looking at how the laboratory
could affect their overall engineering education (i.e. does the laboratory provides practical links to theoretical components)

**Figure 30: Response trends for question 2 of the survey**

**Figure 31: Response trends for question 7 of the survey**
Table 6 shows the additional comments to the survey question “how could the remote laboratory could be improved?” Answers showed students primarily thought improvements could consist of more control over hardware, or to have more instruction on the functionality of the laboratory.

Since the laboratory was an optional resource, it was never the focus of a lecture and students were never given formal instruction on the laboratory. This is something that can easily be modified in future years. Other responses are shown in the table as ‘misc/other’. Again, examples of each response are given.
Table 6: Sample of student responses from survey question 7

<table>
<thead>
<tr>
<th>Response Trend</th>
<th>Example</th>
<th>Percentage of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>More control over hardware</td>
<td>“Could not manipulate controls, nor access sun/weather conditions”</td>
<td>36.4%</td>
</tr>
<tr>
<td></td>
<td>“Including interaction with the configuration of the system”</td>
<td></td>
</tr>
<tr>
<td>Further instruction on</td>
<td>“Lecturers need to explain what the data is to be used for and why it is relevant”</td>
<td>27.2%</td>
</tr>
<tr>
<td>laboratory functionality</td>
<td>“More relating to the encouragement and training regarding the program”</td>
<td></td>
</tr>
<tr>
<td>Misc/Other</td>
<td>“enable access of data for longer periods e.g. past 6 months”</td>
<td>36.4%</td>
</tr>
<tr>
<td></td>
<td>“More time could be made available to the students to learn more or perform more activities or observations”</td>
<td></td>
</tr>
</tbody>
</table>

Figure 32 represents the feedback given from students when asked for general feedback. The responses were separated into either positive comments or negative comments. This was done to allow a general overview of the opinion of students completing the laboratory.
Table 7 shows the comments from students when given the opportunity to provide general feedback at the end of the survey (Question 8, Appendix A). There were very few responses to this section. The responses given have once again been separated into positive comments, negative comments and misc/other.

*Figure 32: Response trends for question 8 of the survey*
Table 7: Sample of student responses from survey question 8

<table>
<thead>
<tr>
<th>Response Trend</th>
<th>Example</th>
<th>Percentage of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive comments</td>
<td>“Overall the remote lab provided a stimulating and informative insight into the function of renewable energy sources.”</td>
<td>60%</td>
</tr>
<tr>
<td>Negative comments</td>
<td>“The data I downloaded was not comma delimited, so it could not be properly viewed”</td>
<td>20%</td>
</tr>
<tr>
<td>Misc/other</td>
<td>“I feel very few students even knew of the existence of the data”</td>
<td>20%</td>
</tr>
</tbody>
</table>

Students were presented with a range of study areas as shown below:

1. Hardware being used
2. Theory of specific lab
3. Calibration principals
4. Practical links to theory
5. Signal analysis
6. General Engineering Principals
7. General feedback
They were then and asked to respond on a Likert scale with how much focus they believed the remote laboratory had on each of the areas. This was in addition to being asked what they believed the primary learning objective was. These objectives were all general engineering objectives instead of ones specific to the laboratory. The tables below show the student responses to each of the survey questions.

*Table 8: Students’ perception on lab focus of hardware being used*

<table>
<thead>
<tr>
<th>Hardware being used</th>
<th>Percentage responses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very little focus</td>
<td>16.67</td>
</tr>
<tr>
<td>Little focus</td>
<td>16.67</td>
</tr>
<tr>
<td>Average focus</td>
<td>29.17</td>
</tr>
<tr>
<td>Large amount of focus</td>
<td>25</td>
</tr>
<tr>
<td>Specialised focus</td>
<td>12.5</td>
</tr>
</tbody>
</table>

The above table (Table 8) shows students’ response to the question “How much focus did you believe the laboratory had on the hardware being used?” After this was done, the following question instead asked for the focus on theory of specific lab (Table 9). This question was asked to act as a balance between the (at the time hypothesised) belief that student responses for the question “What did you believe the learning objective of the laboratory is?”
Table 9: Students’ perception on lab focus of theory of specific lab

<table>
<thead>
<tr>
<th>Theory of specific lab</th>
<th>Percentage responses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very little focus</td>
<td>16.67</td>
</tr>
<tr>
<td>Little focus</td>
<td>29.17</td>
</tr>
<tr>
<td>Average focus</td>
<td>16.67</td>
</tr>
<tr>
<td>Large amount of focus</td>
<td>16.67</td>
</tr>
<tr>
<td>Specialised focus</td>
<td>20.83</td>
</tr>
</tbody>
</table>

The survey then continued asking students to show their perceived focus on calibration principals. This is shown in Table 10.

Table 10: Students’ perception on lab focus of calibration principals

<table>
<thead>
<tr>
<th>Calibration Principals</th>
<th>Percentage responses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very little focus</td>
<td>25</td>
</tr>
<tr>
<td>Little focus</td>
<td>16.67</td>
</tr>
<tr>
<td>Average focus</td>
<td>20.83</td>
</tr>
<tr>
<td>Large amount of focus</td>
<td>29.17</td>
</tr>
<tr>
<td>Specialised focus</td>
<td>8.33</td>
</tr>
</tbody>
</table>

After this, practical links to theory as a lab focus was analysed, with the response shown in Table 11.
Students after this were asked to show their perceived focus on signal analysis. The student responses to this question are given in Table 12.

Table 12: Students’ perception on lab focus of signal analysis

<table>
<thead>
<tr>
<th>Signal analysis</th>
<th>Percentage responses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very little focus</td>
<td>16.67</td>
</tr>
<tr>
<td>Little focus</td>
<td>8.33</td>
</tr>
<tr>
<td>Average focus</td>
<td>29.17</td>
</tr>
<tr>
<td>Large amount of focus</td>
<td>20.83</td>
</tr>
<tr>
<td>Specialised focus</td>
<td>25</td>
</tr>
</tbody>
</table>

The last topic given to students for them to show focus on was general engineering principals. The response students gave to this question is shown in Table 13.
Finally students were invited to show if they believed the focus of the laboratory was on a topic other than those listed above. Student responses to this question are given in Table 14.

**Table 13: Students’ perception on lab focus of general engineering principals**

<table>
<thead>
<tr>
<th>General Engineering Principals</th>
<th>Percentage responses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very little focus</td>
<td>12.5</td>
</tr>
<tr>
<td>Little focus</td>
<td>20.83</td>
</tr>
<tr>
<td>Average focus</td>
<td>25</td>
</tr>
<tr>
<td>Large amount of focus</td>
<td>20.83</td>
</tr>
<tr>
<td>Specialised focus</td>
<td>20.83</td>
</tr>
</tbody>
</table>

**Table 14: Students’ perception on lab focus of General feedback**

<table>
<thead>
<tr>
<th>General feedback</th>
<th>Percentage responses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very little focus</td>
<td>12.5</td>
</tr>
<tr>
<td>Little focus</td>
<td>18.75</td>
</tr>
<tr>
<td>Average focus</td>
<td>31.25</td>
</tr>
<tr>
<td>Large amount of focus</td>
<td>6.25</td>
</tr>
<tr>
<td>Specialised focus</td>
<td>31.25</td>
</tr>
</tbody>
</table>

Since the data asked about each subject individually, a method of comparing results together was required. To do this, each response from very little
focus to specialised focus was given a weighted value, 0-4 respectively as shown in

Table 15:

*Table 15: Weighting given to specific survey responses*

<table>
<thead>
<tr>
<th>Response</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very little focus</td>
<td>0</td>
</tr>
<tr>
<td>Little focus</td>
<td>1</td>
</tr>
<tr>
<td>Average focus</td>
<td>2</td>
</tr>
<tr>
<td>Large amount of focus</td>
<td>3</td>
</tr>
<tr>
<td>Specialised focus</td>
<td>4</td>
</tr>
</tbody>
</table>

After this, a weighted average was discovered. Once this was completed, the values were combined onto a single figure to allow for analysis between the responses from students. These numbers are represented in Figure 33 below.
Most noticeably, ‘Signal Analysis’ and ‘General Engineering Principals’ show as the largest perceived focus of the laboratory with ‘Theory of Specific Lab’ and ‘Practical Links to Theory’ ranking the lowest (ignoring the ‘General feedback’ option).

8.6. Discussion

The laboratory discussed in this chapter allowed students to log into a server from any location and see the outputs of a solar system as it generated power in real time. For feedback, both qualitative and quantitative responses were gathered from students. This section will discuss the results of this survey, starting with the qualitative feedback. This feedback was mostly gained from asking students open ended questions and to allow them to discuss and expand on ideas. It is important to note that this feedback happened in the students’ own time, meaning that it did not occur directly after completing the laboratory. This meant
that students were presented the opportunity to reflect on their learning experience before completing the laboratory.

When looking at the feedback of all students, specific trends started to arise. When asking students the purpose of the laboratory, the students focused on exposure to photo-voltaic cells. This can be seen by the response to Question 2 (appendix 1 – section 12.1.3). With regards to this question, it was positive to see students observing the cell output, however there were very few responses focusing on the long term logged data from the laboratory. Ideally students would have observed the logged data as well as the live data to view the different styles of output. In addition to this, real time visualisation of the solar energy output was another focus for students. A live output of this data was the first thing students viewed when accessing the server. The response trend of leaving lab specific answers when asking general questions was present as was expected in this instance. When asked for the learning objective directly, students would give responses with a purpose related to specific attributes to this laboratory instead of to their overall engineering education, showing student were focusing on the unique aspects of the laboratory instead of its relationship with their overall engineering educational goals.

Specific responses showed a strong belief that the laboratory focused on power generation and photovoltaic cells, which was true. The specific units students were undertaking had a focus in these areas, showing the students’ abilities to link the unit material to the laboratory.
Another trend was for students to leave feedback regarding presenting the laboratory as supplemental information instead of a required practical exercise. Feedback indicated that students expected the laboratory to be directly related to assessment material. Therefore, when viewing the laboratory information, some students did so believing it would directly correlate to marks in a specific assessment, as seen by responses to Question 7 (appendix 1 – section 12.1.3).

Another improvement seen by students’ responses to this question was the observation over the lack of direct control over the solar panels. This was due to hardware limitations, however a future iteration could be created to have this level of control of hardware. What is interesting in this case was student responding with a desire to observe these outputs with different hardware configurations, with responses indicating a desire to further develop their understanding of the effects of hardware configuration on the outputs of the system.

Responses also indicate a lack of individual students being properly introducing the laboratory as an additional resource. A formal induction was only briefly held, and while it would have been sufficient to students willing to investigate aspects of the laboratory themselves, it did not go over logged files or tools such as importing the logged file (in CSV format) into a program such as Microsoft Excel. Another example of this is students requested longer time periods of access. This functionality was already available to the students, since the laboratory was available and accessible 24 hours a day. The laboratory was also set up in such a way that multiple people would be able to access it
simultaneously, meaning that the issue was not with students attempting to access the laboratory at the same time as another student.

This trend of students requesting functionality the laboratory already contained extended to students requesting access to the laboratory log files for data extending back months before students accessed the laboratory. The data students had access to provided logged files as far back as 2014 meaning that while the request for extended periods of time was a frequent request, with students’ even requesting data from the last six months, this data was included in the log files. However this most likely relates to students requesting more instruction on lab functionality, an aspect that can be improved in the future.

Since the students were informed of the laboratory in a forum post alerting them on how to access the laboratory, and in a quick seminar at the beginning of one of their classes, it was possible that students may have missed these instructions. This can easily be improved in future classes by having a lecture informing students of exactly what resources they can access from the laboratory over an extended period, with demonstrations. The instruction manual (appendix 1 – section 12.1.1) provided with students could also be easily updated. Currently this instruction manual focuses primarily on instructing students in how to access the laboratory instead of how to see specific solar outputs once access has been gained. Updating the instruction manual to include this extra information would resolve this issue.

General feedback fell into one of three categories, those being positive, negative and miscellaneous. The overall feedback was positive, however negative
comments were received. Most of the comments were possible to fix, or were due to students not being properly informed on all functionality of the laboratory. In future classes this can easily be addressed and fixed, hopefully leading to a larger number of positive responses.

Of those positive responses, most discussed the ability to assist in visualising system outputs showing this aspect to be a strength of the remote laboratory.

In addition to looking for qualitative feedback, students were also asked to assess what they believed the focus of this laboratory was from a given list of learning objectives. This was done in an attempt to view what relevance the students perceived the information to have over their studies. To do this, they were presented with the question “How much did you feel the remote laboratory focused on the following areas:” and asked to select an option between ‘very little focus’ and ‘specialised focus’. Once again, the learning objectives given for students to analyse are given below:

1. Hardware being used
2. Theory of specific lab
3. Calibration principals
4. Practical links to theory
5. Signal analysis
6. General Engineering Principals
7. General feedback

From the results section, specifically Figure 33, 'General Engineering Principals' and 'Signal Analysis' showed the largest amount of responses from
students, showing that if attempting to have students approach material with these specific mindsets, a laboratory such as this one could possibly be used.

The results for calibration principals, signal analysis and practical links to theory were all bimodal, having trends closer to ‘large amounts of focus’ but also with a large number of students selecting ‘very little focus’. It is believed that this is due to two types of students’ responses, those being either analysing all questions individually, such that students would respond to each sections focus as analysed by itself, or they would place one response as very high with all others as very little, such that all responses would not equate to a high average.

The opposite of this was observed with the ‘General feedback’ option, which showed a large dip in responses showing ‘large amount of focus’. Results support the theory that this is due to the students having one of two opinions, that being that the lab focused on a topic not selected previously, that they would expand on in the survey and select the ‘specialised focus’ option, or they believed the focus was on another area already covered, selecting between ‘very little focus’ and ‘average focus’ for the ‘General feedback’ option.

After analysing the amount of focus displayed, the response with the largest amount of focus was ‘signal analysis’, however this response was only at eighteen percent. When placing the results next to previously completed research, a comparison can be made between this laboratory, focusing on real world systems, standard remote laboratories, proximal laboratories and simulations. Table 16 displays this comparison.
Table 16: Comparison of students’ perceived focus over multiple content delivery mediums (Lindsay, E., Liu, D., Lowe, D., Murray, S., 2007)

<table>
<thead>
<tr>
<th>Category</th>
<th>Higher Mode</th>
<th>Lower Mode</th>
<th>Real world remote laboratory</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Proximal (20%)</td>
<td>Simulation (6%)</td>
<td>16%</td>
</tr>
<tr>
<td>Hardware</td>
<td>Remote (20%)</td>
<td>Simulation (6%)</td>
<td>16%</td>
</tr>
<tr>
<td>Practical Link to Theory</td>
<td>Proximal (13%)</td>
<td>Remote (4%)</td>
<td>13%</td>
</tr>
<tr>
<td></td>
<td>Simulation (25%)</td>
<td>Remote (4%)</td>
<td>13%</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>Proximal (15%)</td>
<td>Simulation (3%)</td>
<td>7% (General feedback)</td>
</tr>
</tbody>
</table>

When analysing the responses found in previously completed studies (Lindsay, E., Liu, D., Lowe, D., Murray, S., 2007), the response rate has a very high number of responses around calibration principals, however after this response the numbers fall to those similar to the responses received in this survey (i.e, between 5-20%).

8.7. Conclusion

While the responses for this study shows a different level of student’s perceived focus, it shows that using different media affects the way students
perceive information and therefore the way students are presented information should be analysed such that the correct content delivery method can be selected.

This section aimed to analyse students’ feedback of their experiences in a solar energy laboratory. The results from this study shows the students’ perceived learning objective skews towards ‘Signal Analysis’ and ‘General Engineering Principals’ for this laboratory. Noticeably this shows that the perceived learning objective was not the hardware being used.
9. Results - Student’s belief of reality, validity of data and presence

9.1. Publications

Journal article covering this chapter submitted to the International Journal of Engineering Pedagogy (iJEP) titled 'Students’ perception of realism in novel solar energy remote laboratory' and is currently under review. Sections of this chapter were published in the AAEE2016 conference, titled 'Solar Energy Logging Laboratory'.

9.2. Introduction

When observing student experiences in the laboratory, both their perception of realism and their involvement in the laboratory become important factors. The motivation of students to learn on their own became important for this laboratory, as students were not completing a directly assessed task, and therefore their motivation to complete the laboratory was linked not to an assessment task, but to gaining a deeper understanding of their engineering discipline.

In addition to this, students must have a reasonable belief of the validity of the data being presented to them, and the validity of the equipment being used to collect this data.

If Kolb’s Experimental Learning Theory (Kolb, Boyatzis et al. 2001, Kolb and Kolb 2005, Abdulwahed and Nagy 2009) is observed in this case, not presenting students with a visual image of the hardware being used and instead only relying
on the data given, specific learners should benefit. Learners of the assimilator style or even those of the converger style should be able to use their abstract thinking to be able to conceptualise the learning process. Students with the assimilator style should demonstrate skills in abstract conceptualisation and reflective observation, while students in the converger styles should be proficient in abstract conceptualisation and active experimentation. However, divergers and accommodators may struggle, as they rely on concrete experience, which this very nature of this laboratory did not assist them with. The learning style could also have effected motivation to complete the laboratory, as when considering the findings of Sansone, Thoman & Smith (Sansone, Thoman et al. 2000), the learning of traditional university aged students, a vast majority of students completing this study, are more motivated by actual graded results, something that was reflected by the feedback of students.

When analysing students’ belief of realism in a laboratory, it has often been observed that a web cam or live updated photos are required to ensure students believe an object to be real. Realism in laboratories is a point of contention, balancing cost of implementation and often students’ time to complete the task (simulating delays for processes to complete) with efficiency of data collection and speed of completion. While the exact amount of realism required is still being observed (Lindsay, Murray et al. 2009), literature in this area (Lowe, Murray et al. 2009) shows that for students to perceive something as being real (in the case of remote laboratories), the real equipment must be shown to them to allow them to establish reality, and a belief that the results are valid because of this. This is also reflected in simulations, where it is shown that the higher quality simulations
reflect a higher degree of presence felt during the experiment (Nunez and Blake 2003).

This becomes important for the laboratory being discussed here, as the data given to students did not include a live webcam feed, or any other type of image used to show live updates of the physical equipment. While there was code developed to be able to do this, it was decided that the effort it would take to implement the physical equipment, plus the additional costing and time required to ensure the case was weatherproof, the equipment would be powered for long enough and that access to the web cam could be gained, it quickly became infeasible to have the setup with a web cam.

What this eventually meant for the study was that for the students completing the project was that the degree of realism they felt relied solely on the data being presented to them, and their ability to analyse the data and understand the system being implemented. While students were told the data was real as part of their introduction to the laboratory, it was never proved to them beyond this point. They knew the hardware discussed in class existed, but a direct link was never proven to them.

This section will contain a case study looking to analyse students’ belief of the validity of the data presented to them in the remote laboratory, as well as their feelings of presence while completing the solar energy remote laboratory. It will provide findings related to the degree of realism they felt while completing the laboratory, as well as provide relevant general feedback from students completing the laboratory.
9.3. Survey setup

As discussed in previous sections, the survey was set up using the survey monkey software suite. This ensured that both the survey was widely accessible, as well as being easy to implement and gather results from. It was made accessible through a link that was emailed to the students’ after completing the laboratory.

The option of using Google docs to create a quiz was considered, however it was ultimately decided to utilise survey monkey. The ability to collaborate, while a useful feature, was not required for this project. Survey monkey offered all required functionality as well as assisting with data collection and analysis.

9.4. Students accessing Laboratory

This section will go into how students accessed the solar power remote laboratory. It will also cover how this could have effected their feeling of presence.

As can be seen in Figure 34 below, the laboratory did not contain a web camera or any other identifying picture on the equipment the data was using. This was an important omission, as students needed to trust in the validity of the data, however it was never explicitly shown to them that the data or equipment being used in the laboratory were real.
The students were presented with the opportunity to access the remote laboratory both in person and via being contacted through their emails as shown in appendix 1 (section 12.1.1). The lecturer would present the students with an overview of the laboratory and how it could assist them in further understanding their subject material. A quick example of how to access the information available to the students was given, as well as an overview of exactly what was available. After this stage, students were invited to ask any questions. Most of these related to accessing the laboratory. After this, instructions were posted on the subject’s unit page that had instructions on how to access the laboratory while not located on campus and exactly what URL was required to access the page. The instructions covered accessing from off campus to allow all students, including those studying
remotely to have access to the data. In this case, a virtual private network connection needed to be established between the user and the university network.

It was only at this stage that the students were told that the data was real. Students were also informed of the location of the hardware (located on campus) and were able to observe the hardware in their own time if they would like, but this was in no way expected.

After roughly a week of having access to the data, students were then emailed a survey link with the ethics approved script (appendix 1 – section 12.1.2). They were able to access the survey from any location and were invited to do it in their own time. Students were also informed that the survey was not related to an assessed part of their unit, and in no way would affect their overall mark. This was an important thing to note, as it led to all participants leaving voluntary information. It was also aimed to have only students who accessed the remote laboratory complete the survey. By stating it was in no way linked to their assessment, it was aimed to have no students complete the survey in hopes of gaining overall marks for their unit, even if they had not completed the survey.

What is important about this method is that students were never in a position to be proven that the data being generated was real. Ideally they would believe it, but since literature states that realism is something that should be made obvious, and that presence is something that is affected by realism, analysing how students were told something is real, and the possibility for students to doubt the validity of this claim is important.
Ideally students will feel although the data they have gathered and observed is real, and hopefully this would lead to a degree of presence in the laboratory being felt. Due to this, a student in theory will not feel although they are accessing the hardware through all networking software instead of accessing software that will simply print out any number.

Figure 35: Student engagement when they feel although they are acting on the laboratory hardware directly

Above demonstrates the ideal scenario, where a student feels although they are working directly with the hardware, instead of feeling although the software is acting as a barrier to the hardware. Below shows a scenario with very little presence felt, where the student perceives the laboratory as a computer program that is giving numbers of a system, but not interacting with the actual system.

Figure 36: Diagram of student perception with very little presence being felt
9.4.1. Survey structure

When attempting to view the students’ perception of realism of the information being presented to them, a survey was created that enabled students to give their responses on a Likert scale relating to how realistic they perceived the data and the equipment of the remote laboratory.

Many of the questions asked were presented twice, with the specific questions focusing on either aspects of a single concept, often asking questions looking for students to state their views on this concept, and then asking for the same information focusing on opposites. An example is given from question four of the survey and question thirteen. These are given below:

*Question 13 - I felt like the data being generated was real*

*Question 4 - I felt like I was completing a computer simulation*

Questions were asked in this style to determine the level of presence felt by the individual students completing the laboratory. The following two questions, question fifteen and sixteen respectively, show this:

*Question 15 - I felt like I was in an environment created by a computer*

*Question 16 - I felt like I was physically in the environment logging data*

It was also decided to determine if students felt that the equipment being used was real. This was to separate the two concepts, real data and real equipment. It was decided to do this to see if the participants could believe the
data being generated was real, but not being generated live. This is reflected by question fourteen, shown below:

*Question 14 - I felt like the equipment being used to gather data was real*

Finally, a presence question was asked to determine if students felt although they were using real equipment. It mirrors the previous question, to determine consistency of results. It was asked at the beginning of the survey to see student responses at the start of the survey before questions directly relating to presence were being asked. This question is presented below:

*Question 5 - I felt like I was completing a laboratory using real equipment*

In addition to the Likert scale style of questions, general questions were presented to the students in an attempt to gain feedback on motivation to complete the experiment as well as possible learning styles. Students were given the chance to answer a question on a Likert scale, and then given an opportunity to provide more open feedback. Question seventeen of the survey demonstrates this concept:

*Question 17 - The remote laboratory was helpful for understanding the topics covered in this unit*  
*Why/Why not*
The other question that will be highlighted in this section was question one of the survey, being the first question presented to students after completing the remote laboratory. Question one is presented below:

Question 1 - I found the remote laboratory intellectually stimulating

Why/Why not

9.5. Student responses

With the results of this case study, there will be two separate sections. One containing all graphs of student responses about their belief of the realism of the data they were collecting, and another containing the feedback regarding the amount of presence felt by those students completing the laboratory.

Firstly, when attempting to determine how real the students saw the data being generated, question four and thirteen can be observed. The response for question 13 (“I felt like the data being generated was real”) is given in Figure 37.
Figure 37: Responses to the question “I felt like the data being generated was real” (Q13)

In contrast to this, the response to question 4 ("I felt like I was completing a computer simulation") is presented in Figure 38. Ideally these graphs would be trending around opposite sides (Strongly disagree and strongly agree).

Figure 38: Response to the question "I felt like I was completing a computer simulation" (Q4)

What is interesting about these results is that while question thirteen strongly skews towards the agree/strongly agree responses, the response to
question four does not show this same strength of correlation. While the ‘disagree’ option is the most selected option, there is still a large number of ‘neutral’ and ‘agree’ options. This is shown in Figure 39.

![Figure 39: Question 4 and Question 13 comparison](image)

In an attempt to show these results in a comparison, the following figure combines the results from the above figures. Before this occurred, the responses from question four were inverted. This means that every response in the agree/strongly agree section is either a statement that they did not believe they were completing a computer simulation OR they believed the equipment being used was real.
As well as this figure, a weighted average from both responses can be created by assigning a weight to each answer as shown in Table 17:

**Table 17: Weighting given to each survey response**

<table>
<thead>
<tr>
<th>Response</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly disagree</td>
<td>0</td>
</tr>
<tr>
<td>Disagree</td>
<td>1</td>
</tr>
<tr>
<td>Neutral</td>
<td>2</td>
</tr>
<tr>
<td>Agree</td>
<td>3</td>
</tr>
<tr>
<td>Strongly Agree</td>
<td>4</td>
</tr>
</tbody>
</table>

After this was done, the total number of responses was multiplied by the weighted value and an average response score was created. With this information, Figure 41 comparing the two could be created. This figure displayed the percentage of responses believing the data to be real to those responses.
believing the data was taken from a computer simulation. This figure is shown below:

Figure 41: Comparison to the responses from Q4 and Q13

After this analysis, a similar study on the realism of the physical equipment can be completed. This was done in order to both determine their established reality of the equipment as well as the belief in the validity of the results presented. Once again looking at student responses, the following graphs can be generated. Specifically from question 14 and question 15. Question 14 looked into the students’ belief in the validity of the equipment by asking them to answer the question “I felt like the equipment being used to gather data was real”. The responses for this can be seen in Figure 42
Figure 42: Responses to the question "I felt like the equipment being used to gather data was real" (Q14)

As with previous questions, question 15, asking students to answer the question “I felt like I was in an environment created by a computer”, was the opposite of this. The students’ responses can be seen in Figure 43.

Figure 43: Responses to the question "I felt like I was in an environment created by a computer" (Q15)
Once again the results for question directly asking if the participants believed the equipment (much like the data) was real had a very strong skew towards the ‘agree’ and ‘strongly agree’ options, but again when asked about being in an environment created by a computer, the results were near identical values with the exception of strongly agree, which fell significantly shorter of all other values.

When compared on a single graph, the strength of responses can be seen. It is interesting to note that while question 15 (I felt like I was in an environment created by a computer) did trend towards neutral/agree, the strength of this trend is not nearly as strong as with question 14 (I felt like the equipment being used to gather data was real). This observation is shown in Figure 44.

![Question 14 and Question 15 responses](image)

*Figure 44: Question 14 and Question 15 responses*

Following the steps shown previously, when combining the two graphs into a single figure for comparison, the data appears much more skewed to the ‘agree’ and ‘strongly agree’ sections. Again, the data for question 15 was inverted
to better reflect the students’ belief that the data was not gained from a computer simulation. This figure is given below:

Figure 45: Combined data from Q14 and Q15

This data being given a weighted average in an identical manner to the one used previously can also be created. This information is presented in the below figure:

Figure 46: Comparison of responses from Q14 and Q15
Question five of this survey asked students to rate their belief that they were using real equipment similarly to question fourteen, however it did not reflect the same responses. The student responses were again skewed towards agree, however the ‘neutral and ‘disagree’ options had a higher percentage of responses than in other, near identical questions.

Figure 47: Response to the question "I felt like I was completing a laboratory using real equipment" (Q5)

When comparing the responses to question five and question fourteen, the following graph was created:
However, to easily compare this figure, when the two results are combined the following figure is created. This figure strongly skews to the ‘agree’ response, as do other similarly asked questions.

**Figure 48: Comparison of the responses to question 5 and question 14**

Once again this figure can be used to compare to question 15. This is shown in Figure 50.
When looking at presence felt by the students, question sixteen and seventeen of the survey can be used. The responses from these questions asked students to rate if they felt physically present in the experiment. The student responses are given below:

**Figure 50: Comparison of Q5 and Q14 combined with Q15**

**Figure 51: Responses to the question "I felt like I was physically in the environment logging data" (Q16)**
This graph does not show strength to any of the responses, with ‘neutral’, ‘agree’ and ‘disagree’ all having extremely similar response rates. This shows a very neutral feeling of presence.

9.6. Discussion

When comparing the figures generated by responses from the survey, a vast majority of the replies indicate students perceived the data as being real, and perceived the equipment is being real. These findings oppose the literature that states hardware and the data taken from this hardware must be shown and proven to be real to have students believe it is real.

Specifically, when observing Figure 37, a very large trend towards the strongly agree/agree options. Figure 38, looking at if students believed they were completing a computer simulation showed a trend towards disagree.

What is important in this analysis is that students must be able to believe in the validity of the results. It was aimed to observe, but also to have a high degree of presence felt in this laboratory. By increasing the students’ belief that the data was real, and therefore valid, ideally this would increase their presence in the laboratory. This was also observed in Figure 41, which after weighting showed 64 percent of students believed the data was real compared to the 36 percent of students who did not.

After this an analysis on the students’ belief in the realism of the equipment occurred, with Figure 42 showing that students’ responses trended towards the ‘agree’ and ‘strongly agree’ option. What is interesting is when asked if students’ felt like they were in an environment created by a computer, meaning
the equipment would not be real, as shown in Figure 43, the results trended towards neutral/agree. What is important to note, and demonstrated in Figure 44, was that the strength of correlation in belief that the equipment was real was much stronger than in Figure 43. Figure 42 had a much larger majority of responses in the ‘agree’ and ‘strongly agree’ options, with much fewer ‘disagree’ and ‘strongly disagree’ options being selected by students. This was further demonstrated by the weighted responses shown in Figure 46. This figure showed 61% of students believed the equipment was real, compared to the 39 percent that did not.

What is important to note with the results found was when asking two similar questions, those being ‘I felt like I was completing a laboratory using real equipment’ and ‘I felt like the equipment being used to gather data was real’, the responses gained were similar, but not identical. This is also reflected in Figure 48, which directly compared the results. It shows the importance of analysing what questions need to be asked, as well as having multiple questions to verify results, which this methodology incorporated.

Finally, looking at presence in the laboratory, the question ‘I felt like I was physically in the environment logging data’ was asked to the students, with a very neutral response returned. This is also to a lesser degree reflected by Figure 43, which looked at students feeling like they were in an environment created by a computer. Since the responses to this question trended towards agree, and the responses to students feeling physically present trended towards neutral, a neutral to lack of presence in the laboratory can be established. This is most likely
due to the outputs of the laboratory being very minimalistic, with only the graphed data being displayed, meaning it would be hard for students to visualise the actual equipment. From previous figures that show students believed the data and equipment was real, showing that for students there is a separation between the software displaying the outputs and the hardware generating these outputs.

In future iterations of the laboratory, a web camera could be installed to give students a live view of the logging equipment or the solar panels. This would hopefully help to remove the separation, or lack of presence between students and the data being generated.

Having students believe the data was real appeared to have very little bearing on students’ perception of presence within the laboratory, with very few individuals feeling either extreme presence or a lack of presence. While a web camera may not be required to prove the data was genuine, any feedback on the laboratory may assist in creating a feeling or perception of presence. However this web cam may not need to be installed to increase the students’ perception of realism, only to improve the amount of presence felt. This is important as it means that by analysing the method in which we present students with additional information, it can alter their belief in the validity of the data.

9.7. Conclusion

In this section we have observed the feeling of realism of students completing this laboratory, as well as the presence it created for the students. While students did not indicate a strong feeling of presence, it was found that students perceived the data and equipment to be real without having to show them the physical
logging hardware. This finding opposes current literature on remote laboratories that focus on showing models instead of real world systems.
10. Analysis

This chapter will complete a discussion and analysis of the results displayed in previous chapters. It will be separated into sections addressing each results chapter, as well as further sections discussing possible improvements to the laboratory, focusing both on student experiences and the actual laboratory system, as well as both hardware and software. The chapter will conclude with a discussion on the educational requirements of engineering education institutes both in Australia and globally, and analyse what competencies students must display in accredited degrees, and how this laboratory may assist in allowing students to display those competencies.

10.1. Construction of the laboratory

The use of software design as a tool to assist in creation and ease of access for the remote laboratory is not something that should be ignored. So much of the end users experience is based around essential elements such as how the data is gathered, as this affects how the user can receive and interpreted the data, as well as how it is displayed. By using in house software, a greater degree of control over these elements was established. This was not the first choice of system architecture however, as software to assist in the setup of remote laboratories does exist. A common selection is the SAHARA labs (Lowe, Machet et al. 2012), which assists in setting up both the web interface, remote laboratory communication and a scheduling system. Overall it is a very robust system, and is capable of handling both active and batch laboratories, however for a system such as the one required, this extra functionality was not always required. An example
of this is having a scheduling system for remote laboratories. This functionality exists as often hardware cannot be shared by multiple students simultaneously as they complete experiments or gather data. By having a scheduling server automatically set up, students in SAHARA labs can set up a time they are guaranteed access. While this is a very powerful tool, the laboratory design chosen allowed for multiple people to access the laboratory simultaneously. This is due to the fact that the laboratory existed primarily to log outputs of the system, and therefore student interaction was with these outputs. This meant that parameters were not changed by the students, and therefore having a system isolating students to a single hardware set was not required.

This concept was displayed in Figure 15, Figure 16, Figure 17 and Figure 18, which was used to show the difference between the raw data generated by the logging equipment and the data shown to students accessing the laboratory. Since Figure 15 showed thirteen data points in total, ranging from data id number 341362, with 28,459 joules of energy being generated over a 10 second period to data id number 341360, with 31,940 joules, students could easily see the erratic nature of renewable energy generated by this system. They could easily observe how over a relatively small timeframe, in this case Figure 15 showing a time range of two minutes and fifteen seconds, a large variance in output power can be observed. By giving students access to the data both visually and numerically (downloadable in CSV format), students were able to determine for themselves how they best analysed the output information, that being the power generated by the renewable energy solar system. This data was easily available to multiple users simultaneously, meaning students could all access the same information
regardless of the number of active users. This allowed for the laboratory to not require a ‘reset’ state.

Graphically, students had access to the same data but in a more visual format. Figure 16 shows the data over a 120 second time frame, ending at 20,044 joules of data being generated, however having an incredibly large drop in energy generation to less than 16,000 joules of energy in the same time frame.

In addition to this, long term studies could also be easily done with the raw data generated, as a data point every ten seconds was generated. This is a substantial increase to the number of data points generated before the logging hardware was added (originally being one every ten minutes), and is only limited by the inverter speed. The inverter was only able to generate a new data point every ten seconds, meaning that in future projects using different logging hardware, this sample rate could easily be increased using the pre-existing code in order to allow more usability. Unfortunately for this project, as the usability was gated by the speed at which the inverter updated its power generated, sample rates under ten second increments were not possible.

Figure 18 also shows students’ data in a graphical format, however this data shows a single snapshot of a two hour period. This was done in order to show trends over a larger timeframe, yet still allow for the smaller variances in data generation to be observed. Through a time period starting at 12.42AM and ending at 2.56PM, the watts generated can be observed. This change from joules to watts also allowed students to gain exposure to different methods of measuring renewable energy systems, being able to observe data in both joules and watts. A
large peak slightly less than 3,000 watts can be observed at 1.35PM yet at
12.52AM, there is less than 1,000 watts. It should be noted that the y axis of the
graph, in this instance showing the watts generated, begins at 500 watts. This
number will automatically update to allow for larger ranges of data, but will also
assist in fitting all required information onto a single graph for smaller screens.

Figure 19 is an example of why this auto scaling of data might be beneficial, as
mobile screens do not conform to the standard ratio expected of modern
computers. Figure 19 displays data generated over an 80 second timeframe, being
measured in joules. An issue observed with this was the fact that the graph would
try and display the entire data range, making it hard to observe the small numbers
due to their font size, however pinch zooming was enabled for this view, meaning
that exact data points can be observed. Figure 20 demonstrates this, and it can be
observed that Monday August 12 at 3.42PM, 8,547 watts were generated. Figure
19 and Figure 20 also show the IP address used by students to access the
laboratory. This could easily be changed either by changing the static IP address
of the server, or by domain hosting. While having a domain name would have
been a nice addition, it was decided that other features deserved priority and it
was eventually decided not to be included.

The benefit of this access method was that students were all able to access
the laboratory regardless of their chosen device. The server structure was set up
to ensure that a mobile interface was not required, yet the same functionality was
still provided. This was done to ensure that any operating system with any web
browser would have access to the laboratory.
The choice to use a raspberry pi to log all data communication between the inverter and other logging hardware meant that a script could be used to listen to all communication and send data requests as required. This allowed the laboratory architecture to be able to easily be modified by changing what could be simplified into a single script, meaning the software could easily be modified for other remote laboratories, to show students other working systems. Due to this, the flexibility of the laboratory is extremely high, as the section of code required to enable data logging for the laboratory has been isolated, while all other communication is handled automatically in python by the threading technique used. The laboratory was set up such that all logging equipment could connect to the laboratory hardware via USB input, meaning that any changes to equipment could easily be handled by again making sure all outputs connect to a USB device.

The specific section of code responsible for the call and response of data to be sent to the web server was handled by a batch file, and therefore every time it was called would run a simple script to collect the required information. The importance of this isolated script is that simply editing a single file can cause the entire laboratory to easily communicate with an entirely different system. All other communication not required for the laboratory is handled automatically and would not need to change. Having a system set up that allowed for simple modification to adapt to new hardware, while not a requirement, means that future research with a similar system utilising the same output style will be significantly easier to implement. An example of this that was a consideration was to add outputs from a wind turbine to the outputs of the laboratory. To implement
this change would require the script to be modified to instead call for information from the wind inverter (in this case changing a single number in the code) instead of from the solar inverter.

Server side, information for the laboratory is sent using a UDP instead is TCP/IP. This was done to capitalise on the loss tolerance of the UDP connection, primarily the fact that the server or logging hardware could be reset, and as soon as properly running, easily re-establish communication without the need to set up a handshaking protocol again. In this case it meant that if for any reason communication was lost, it was often faster to reset the hardware than to debug. This would lead to roughly six data points being missed, however this was deemed an acceptable loss considering the time it took to debug the server could easily be longer than this.

This choice of hardware also gave advantages to setting up the laboratory in the fact that the raspberry pi 2B has 4 USB inputs as well as Ethernet connections for internet access. In future versions of the project, upgrading to the raspberry pi 3 would be beneficial, as it has wireless functionality, as well as higher processing power which may be required in future applications. When considering budget, the raspberry pi can be found online for roughly $60AUD depending on the distributor. While this was not the only hardware required, as the server was hosted in a different location (although could easily be hosted on the pi), and the inverter architecture was pre-existing, the cost of the entire projects hardware elements needing to be purchased were well under $100.
The server was a simple Linux computer with the LAMPs software suite installed. This software suite was chosen in order to make it much easier to both log all data values in a MYSQL database, as well as to easily provide a web interface for all users. PHP and HTML programming was all that was required, and web browsers can connect to these pages by default. This led to all devices being able to access the server without issue, regardless of the platform or operating system. The intention here was to have a single unified interface for all accessing platforms, and to have all data available to the students without the need to install any extra software. The reasoning here being it would be hard to expect students to install software on their computers for something that is not assessed, and so it was decided early in the development process that any software would need to be able to run on any device without needing pre-existing software to be installed. The use of an html interface was therefore vital.

When designing the laboratory, the ease of use was an important metric to consider. After determining that Macintosh devices (MacBook’s and iPhones) were the most used mobile devices, specific design considerations in future iterations must be considered. The figure for this is shown in Figure 1. An example of this design consideration is the use of adobe flash. Since Macintosh devices cannot use this software suite, its inclusion in any laboratory would essentially remove 49% (refer to Figure 23) of the available users, or at least remove their preferred access mode.

Chrome being the most popular browser to access the laboratory, with 64% (Figure 24) of all accessing students using chrome, also meant that designs in the
future should ensure Chrome as a viable browser. Firefox web browser was the second most popular at 29% of all students using this to access the laboratory. Safari and internet explorer were the least used browsers to access the laboratory, with 4% and 3% of students using these browsers respectively.

When observing the students accessing the laboratory as shown in Figure 25, there is a trend of peaks a week apart. The first of these occurring in week one, when students were first informed of the laboratory, and week 2, after they were reminded to use it as an additional resource. After these two lectures, a reminder email was sent out to all students aiming to again inform them of the laboratory, but to also give them a chance to complete the survey in order to gain their usage data, as well as information found in the first results section, discussing students’ engagement with the remote laboratory. This also corresponds with another peak in access. This data shows a spike in activity after students were reminded of the laboratory. Because this laboratory wasn’t assessed, it cannot be used to line up with an assessment piece, and therefore was not analysed with respect to any assessment pieces.

While spikes in access can be seen with every reminder, the unique visitors to the laboratory were 73% of accessing students. This meant that only 27% of the accessing users were returning users, as shown in Figure 26. It is true that primarily users were unique, first time viewers, however the laboratory was not set up to require multiple visits, so a low number of returning users, in this case a little over a quarter, is to be expected.
With students accessing the laboratory from a wide range of devices, there was only ever one email from a student asking for help. In this case, it was due to the CSV files not properly downloading to the student’s device. This was easily addressed, however in future more assistance to students can easily be given to ensure this issue does not occur again in the future.

10.1.1. Students’ willingness to adopt remote education

The ability for students studying primarily on campus mode and their ability to adopt remote education focused techniques was analysed in this document, with a large number of the students choosing to forgo their laboratory experience in favour of a remote mode of study. This was done by presenting on campus mode students with the opportunity to complete their practical component of their electronics study either in person with a demonstrator present, or via tutorials posted to the cloud that were available to them remotely.

Both delivery methods were presented to students, with the recommendation being that if they required hands on experience before a formal assessment that the students opt in to attending the practical sessions in person, however the online videos would also be sufficient. It was found that with the exception of a single student in the first week of practical sessions, all students in the class opted to view the practical content online instead of attending in person. While this means they missed the theory in person, there were assessments requiring them to demonstrate their practical knowledge, so this content was still assessed.
What this shows is an on campus student’s willingness to adopt a remote style of education. By giving them the second option, the flexibility of learning becomes much larger, and students can opt in to the style of study that works for them. Part of adopting a new engineering course is understanding how students wish to study, and finding ways to provide that. With a laboratory such as this one, students located anywhere in the world are still able to gain exposure to a renewable energy system without needing to be located on campus. However, as demonstrated by the on campus students in this study, regardless of the current method of study, that being on campus or remote, students offered the flexibility of study modes will still opt into ones that may not be primarily associated with their primary mode of study.

This is important to note, as primarily the students used in this study were located on campus, meaning that it must be established that on campus students were willing to adopt a remote style of learning. Without this establishment there was no guarantee that students would be willing to participate in this study. It also allowed for the establishment that students would be willing to adopt new engineering educational technologies, meaning that a transition to design based learning, and having laboratories updated to reflect this change in educational philosophy would be possible.

10.2. Students’ perceptions of the laboratory

When analysing students’ behaviour in the laboratory, an important consideration of this study was looking at how they would approach the remote laboratory as a learning medium. In order to solve this, students were both asked
for a written response to what they believed the primary learning objective was and the focus of the laboratory. Students were asked to give their response to these questions either as a written response, allowing for a wide range of answers to be given, or on a Likert scale of pre-determined responses.

The purpose of both styles of question is that when given an option to give an extended response, it has been observed that students are likely to give laboratory specific responses, while allowing students to rank the learning relevance to pre-determined responses allows for the analysis of this laboratory, and how students will perceive its learning objective, to other styles of laboratory.

Firstly students were asked to give a written response to the question ‘What do you feel the primary learning objective of the remote laboratory was?’ This question in the survey was intentionally asked first as not to influence the responses from the Likert scale style question. In theory if students chose responses from a Likert scale, they likely would respond in a short answer question with one of the previously listed responses.

From the responses gained, a trend was established with two responses being the most common. Table 4 shows that of the responses, the majority (87.2 percent) of responses fell into one of two categories, those being to allow students to see real time visualisation of system outputs, and to observe power in photovoltaic cells. The exact percentages of each response shows that the percentage of students believing the laboratory objective was to observe or see real time visualisation of system outputs had 31.6 percent of total responses, slightly less than one in every three. The response from students stating that the
laboratory showed power and photovoltaic cells was over half the responses, gathering 52.6 percent of all responses.

From the responses gained, the expected trend of lab specific responses was observed. Having 52.6 percent of all responses stating the learning objective was to observe power and photovoltaic cells showed students could correlate the information being observed to the system the data was coming from. This is important as the laboratory itself has a reference to the renewable energy generation method in the menu system and the page name, but there is no photo of either the inverter or the PV cells. Students showing the ability to link the outputs shown to the system used to generate them is an important skill for developing engineers, and with the ‘ability to work on a wide range of engineering tools for analysis, simulation, visualisation’ (Program-Accreditation Engineers Australia, 2017) being a prerequisite competency for all qualified engineers according to the guidelines on the Engineers Australia (EA) accreditation process, the governing body and auditors for all engineering educational programs in Australia. Having students perform laboratories where they are required to show competencies’ towards this goal should be a requirement for all laboratories given to students.

Similarly to this, the students’ perception that the laboratory learning objective was to observe or see real time visualisation of system outputs had 31.6 percent. In this case, students must have been linking the outputs to the real world system they were coming from. The ability to link the output numbers and graphs to the system they appeared from is an important skill to have. Again, linking this
information to the physical system it was coming from with no actual evidence of
the systems existence is an important thing to note. While it is true the system
was set up to take real time outputs from a solar inverter, this fact was never
overtly proven to the students.

An analysis of presence will be discussed later in this chapter, but it is
important to note that the student responses indicated they believed the validity
of the data, indicating a slight feeling of presence, yet when being asked about the
presence they felt directly indicated a much more neutral feeling of presence.

Of the remaining responses, totalling 15.8 percent of the total responses
received, being less than one in every six students, students indicated responses
that did not fit into one of the above two categories. These responses indicated
technical knowledge as the learning objectives, such as the example given in Table
5. There were also practical learning objectives, such as the response indicating
that the objective was to provide outputs to students that cannot attend class.

While this is a strength of offering these live outputs of the system, it is
understandable that a majority of students did not consider this to be a primary
learning objective. It is an important note that it shows that students were
analysing the method that content was delivered, and the possible advantages of
such a content delivery system.

Students were asked to observe any improvements they could imagine in
the system. The intention of this question was to gather possible changes, but also
look at features students were using, and would like to see further developed. This
survey question allowed for a written response, with students giving a wide range of answers. These responses can be observed in Table 6.

The largest group of responses were regarding interactivity of the laboratory, with 36.4 percent of students completing the survey commented on this. They requested the ability to interact with the photovoltaic cells, specifically students requested the ability to adjust hardware properties such as cell angle or direction. This control was not given to the students as the system was being utilised for more than just this laboratory, however future iterations of the laboratory could easily include a second PV cell that has this inbuilt functionality. In this case, it would also require a design overhaul of the web interface, as theoretically multiple users could request specific and opposing hardware changes. To solve this, a scheduling system such as that found in SAHARA labs could be used, or a timer allowing only a specific number of angles be selected, with a queuing system. For this second option to be a viable alternative however, would require significant further development and testing before it became available to students. The potential issue is that having to many people adjusting the hardware over small periods of time could damage the hardware, or stop it from functioning as expected.

Of the feedback that was received from question 7 as shown in Table 6, 27 percent of the responses focused on accessing the laboratory with no instructions. This represents over a quarter of participants. During the introduction to this laboratory the students were given a brief instruction on how to access the laboratory, and how to access all of its content, however instruction stopped at
this point. Due to the fact that the laboratory could be accessed at any time, the students completing the laboratory were not given personal instruction as they viewed the data it presented, meaning that if something went wrong, or they were unable to view a specific piece of data, there was no formal instruction or even a present instructor to assist them. This clearly was an issue, and therefore in future a more detailed instruction will be given. For reference, the instructions given to the students are available in appendix 1 – section 12.1.1.

This becomes an important thing to note, as the layout of the laboratory was designed with the intention of being easily navigable. An example of this is the menu at the bottom of the page that remained constant regardless of the information being accessed. This was done to have as little information change while accessing different pages, as this would allow students to focus on what was changing, which would have been different solar outputs or different time periods to view the information.

In particular, these responses also indicated that students accessing the laboratory were looking for information that would be directly relevant to their assessment. As this laboratory was presented to the students as supplementary information, this was not the case. Due to this, students completing the laboratory expecting to find a formal assessment would have been either frustrated by this fact, as they were not using the laboratory as a learning device, but simply as a means to complete a formal assessment.

Of the responses that remained, 36.4 percent, students requested information such as having the data available for a much longer period of time, or
having data logs available for further in the past. Data logs for the remote laboratory exist as far back as 2013, and all individuals accessing the remote laboratory have access to this data. This again links back to students not accessing the data, however when looking at students’ behaviour in the laboratory, many individuals would access the home page, showing live updates, but progress no further. Students accessing only the front page would not have access to the logged files, meaning either there was not enough instruction given to the students on how to access different pages through the menu, or students were not willing to explore all functionality of the laboratory.

After looking at feedback from students about their experiences in the laboratory, the following questions aimed to determine the perceived learning objective of the students. This question had already been proposed to students, expecting a written response instead of a Likert scale style response. The change in this section was that they were given a chance to give their responses with respect to a list of pre-determined responses. This was so that the students were given a chance to leave both a written response, expected to be lab specific, and a learning objective from the following list:

1. Hardware being used

2. Theory of specific lab

3. Calibration principals

4. Practical links to theory

5. Signal analysis
6. General Engineering Principals

7. General feedback

These learning objectives are taken directly from the survey given to students. All questions asked to students in this survey are available in appendix 1 – section 12.1.3.

Students were invited to answer each question on a Likert scale, meaning that they were requested to give a response for each of the learning objectives given. By doing this, a direct comparison between the responses could be obtained. What was found was that there were two types of responses. Some students would give a single objective a very high mark, and all others a low mark indicating their preference, while others would give all learning objectives different score depending on their perceived relevance, while not lowering the scores of all others. In this sense, some students gave a ranking of their perceiver learning objective while others gave a mark for each, giving feedback based on how relevant each learning objective was in isolation.

The method used to combine the feedback together involved assigning a weight to each response such that a ‘Specialised Focus’ response from a student would apply a larger weight to a learning objective than a strongly disagree. The weighting numbers are given in Table 15. What is shown is that a ‘Very little focus’ response gained a 0 weighting, while a ‘Specialised focus’ response gained a weighting of 4. After this was done, the total number of responses in each category was multiplied by the weighting of that category, and with this an average response value could be created.
The purpose of this average weighted response was to allow each category to have a single number that could be compared to all other categories. For example, if the response for one of the learning objective categories contained a single ‘specialised focus’ response, but all others were ‘little focus’ or ‘very little focus’, it should have a small response number. Opposite to this, if students completing the survey primarily responded to a specified learning objective with ‘specialised focus’, this learning objective would gain the largest response number.

With this, a method of comparing all responses together had been established, the values were combined into a single figure, as shown in Figure 33. The figure shows that of the students surveyed, the largest percentage of students believed that the primary learning objective of the laboratory was signal analysis. This was the hypothesised outcome, as the method in which data was presented to the students consisted of outputting the renewable energy reading taken from the solar inverter into a single, continually updating graph. It is understandable that students believed with this system that signal analysis was a primary learning objective. What is interesting however is that while the data was presented to them in a single graph, the graphical information was the outputs of a solar inverter, and was not a signal from another application or device.

After signal analysis, the following highest perceived focus of the laboratory was ‘general engineering principals’ and ‘hardware being used’. It was originally hypothesised that ‘hardware being used’ would be seen as the largest laboratory learning focus due to the laboratory introducing students to the solar laboratory system, however that was not the case.
After this, the highest response of students’ perceived focus was ‘theory of specific lab’. This would be students perceiving the laboratory theory as being the interpretation of real world solar energy system outputs. This links to the student responses to the question asked previously, asking for their perceived learning objective. It should be noted at this point that a majority of responses to this question were lab specific, so when looking at what students perceived were the ‘lab specific’ learning focus, this would be referring to topics such as real time visualisation of outputs as well as topics such as power and photovoltaic cells.

After these laboratory focus topics, the following responses focused on ‘calibration principals’ and ‘practical links to theory’. These having low percentage of student responses would be due to the fact that the laboratory did not contain a calibration aspect. What was unexpected was the ‘practical links to theory’ being below this, considering the laboratory displayed the real world outputs, showing what would appear in a practical system. However, students appeared to have seen the links between practical outputs and the theory behind them to not be a focus.

The lowest response gained by students was the ‘general feedback’ option, where students were invited to list their own laboratory focus. The responses to this category mirrored those responses from the previous questions asking about the students’ perceived laboratory focus, those being laboratory specific responses. These learning objectives were given a very small focus by the students completing the survey.
These results can be used to compare with previous research already completed in the field of engineering pedagogy (Lindsay, E., Liu, D., Lowe, D., Murray, S., 2007). This study aimed to analyse the different perceived learning objective, or laboratory focus over three different educational mediums, those being in person, or proximal, through a computer simulation or via remote laboratory, where the remote laboratory aimed to show students a model of a working system.

When analysing the differences in perceived learning objectives and laboratory focus, it has been established that the medium that students use in complete practical experiments affects the learning objective they perceived from the learning material. This laboratory differs from those already being compared in that it introduces the real world element of an actual working system to the laboratory, instead of a model of said system housed in a remote laboratory. By giving students access to the outputs of a currently working system instead of the model, the way they perceive the learning objective will to change.

What this means is that a learning experience can be tailored to the students depending on what specific focus the educational institute desires the students to have. An example of this is looking at Hardware of the specific lab, where 20 percent of students completing a model based remote laboratory found this to be focus of the laboratory, while only 16 percent of students completing the remote laboratory focusing on a real world system perceived this to be the primary focus. It was interesting in this study to note that students completing the lab on campus showed the same response as those completing the practical
session in a model based remote laboratory format. When making this comparison, it should be noted that using simulations as an educational medium saw students have as low as only 6 percent of students perceive this as the focus of the laboratory. This comparison can be seen in Table 16.

This can be compared to a specialised focus such as practical links to theory, where it was shown that 13 percent of those students completing the laboratory in an on-campus mode say the focus as being practical links to theory, the same as the laboratory discussed in this chapter. Remote laboratories however saw this number be only 4 percent, a clear difference in perceived focus.

With this information the educational experience for students completing their undergraduate studies could be analysed to observe what focus students are approaching their learning with. Currently, some engineering educational institutes are moving to a more design based learning curriculum, and by knowing what learning objectives and focus the students are approaching their practical content with, the educational experience can be used to guide students to specific learning outcomes.

10.3. Students’ belief in the realism of the laboratory

Students completing the remote laboratory were given access to the online resources which gave them a view of the data as it was being generated live. This information however was never proven to be real to the students, as devices such as web cameras were never utilised. While giving students this information is important, the students must believe in the validity of the data, as well as the validity of the equipment being used to generate the data.
It is important therefore to note that while the data was never proven to be real through a video feed, the students were told they were accessing real solar inverter outputs. This was done both when they were introduced to the remote laboratory during a scheduled lecture and through the online resource given to the students telling them how to access the remote laboratory.

In order to assess students’ belief in the validity of the data being presented to them, they were asked two different questions, and invited to give their response via a Likert scale. For validity of the data, the questions were “Question 13 - I felt like the data being generated was real” and “Question 4 - I felt like I was completing a computer simulation”. These two questions should in theory gather opposite results. This was done in an attempt to ensure the survey would give students opportunity to properly express their opinions, and to make sure that the data received would be accurate.

Students’ responses to the question “I felt like the data being generated was real” was given in Figure 37, where a very strong correlation to agree and strongly agree can be observed. The agree option was selected by 50 percent of students completing the laboratory, while the strongly agree option was selected by 37.5 percent of all students completing the survey. This accounts for 87.5 percent of all responses for this question. The remaining response, being 12.5 percent of all responses were all either neutral, disagree or strongly disagree. Each of these responses indicated very few students felt either neutral or disagreed with the statement, indicated by the fact that of these responses, no individual section had over five percent of the total responses.
In comparison to the above question, when students were asked for their belief that the remote laboratory was a computer simulation, specifically question 4 of the survey given in appendix 1 (section 12.1.3), the responses did not display the same level of strength of response. While a very large percentage of students indicated they disagreed with the statement, a percentage of students indicated their agreement to the statement. By far the largest response received was disagree, with 35.5 percent of all responses from students indicating this option. However, after this the next responses were agree and neutral, with 22.5% of the responses in these categories. While it does indicate a majority of students did not believe it was a computer simulation, some students disagreed, and to a much larger extent than was shown in the response of question 13.

The final responses were separated over the strongly agree and strongly disagree options, with 12.9 percent of students selecting the strongly disagree option, and the remaining 6.45 selecting strongly agree. It should be noted here that students who believed the data was not generated from a computer simulation should have been selecting the disagree option for this question.

Since these two questions were related to each other, a direct comparison was then made. This involved combining the two responses for the questions. This was done via combining the ‘strongly agree’ option for question 13 with the ‘strongly disagree’ option from question 4. The ‘agree’ option from question 13 was combined with the ‘disagree’ option for question 4 and so on, until both responses could be displayed on a single axis. This information was displayed in Figure 40.
Before the analysis of both graphs combined, an important thing to take note of is that when comparing the raw values of each graph on a single axis, as shown in Figure 39, the ‘agree’ response for ‘I feel like the data being generated is real’ shows significantly more responses than any other response in the figure, showing the high percentage of students selecting that option, and the very little deviation from this option, while ‘I feel like I was completing a computer simulation’ had a larger amount of deviation from the most selected answer.

After combining the responses from both questions, Figure 40 can be observed to show the outcome. This outcome should represent the amount of students believing in the validity of the data, combining both the responses of students believing the data was real with the inverse of students believing it was a computer simulation. The largest response was ‘agree’, having 41.8 percent of all responses in this category. After this response was ‘strongly agree’ with 23.6 percent of the total responses. These responses equal 65.5 percent of all responses gathered. Of the remaining 34.5 percent of responses, slightly less than 30% fell between the ‘neutral’ and ‘disagree’ options, while less than 6 percent resulted in a strongly disagree option.

This data was used to indicate that students believed in the validity of the information being presented to them, regardless of the fact that no web camera was used to display the solar inverter or solar panels. Believing in the validity of the data should assist in increasing the feeling of presence, which will be discussed further in this chapter.
After this step was completed, a weighted average was created from the raw data, determining the average response from students as a numerical value. This was done by applying a weight to each response, as shown in Table 17. When this was done the average response was found. This was done using the below equations:

*Weighted average of students who believed data was real* = \( W_r \)

*Weighted average of students who believed data was computer simulation* = \( W_s \)

<table>
<thead>
<tr>
<th>Students who believed data was from real equipment</th>
<th>Students who believed data was taken from a computer simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{W_r}{W_s + W_r} ) * 100</td>
<td>( \frac{W_s}{W_s + W_r} ) * 100</td>
</tr>
</tbody>
</table>

From these equation, the average response of students believing the data was the result of a computer simulation compared to the people who believed in the validity of the data could be determined. It was found using this method that 35.79 percent of students believed the data was the result of a computer simulation, while a much larger percentage, 64.2 percent believed in the validity of the data. This information is represented graphically in Figure 41. What this shows is that when looking at the data as one of two options, those being that students either believed the data was real or students believed the data was a computer generated simulation, there is almost double the amount of students believing the data is real.
While having the data represented as 2 single numbers, this does not take into account the fact that by far the largest majority of responses fell into the ‘agree’ or ‘disagree’ categories for question 13 and question 4 respectively. Therefore looking at the data taken from the Likert scale gives a more accurate representation of the students’ responses and the trends of these responses, specifically the low deviation in question thirteens responses compared to question four.

After the analysis on realism of data was completed, students’ belief in the realism of the equipment being used to collect the data was also undertaken. This is an important distinction to make, as it ensures that students who believe the data is real also accept that the equipment being used to generate the data is also reliable. It could also shed light into those students who believed the laboratory was a computer simulation.

This section of the study will primarily focus on the responses given in question fourteen and question fifteen of the survey given to students. For all questions given to students, please refer to appendix 1 – section 12.1.3. Question fourteen of the survey asked students to respond on a Likert scale to what extent they believed the equipment being used to gather data was real. Opposite to this was question fifteen, which asked students again to respond on a Likert scale to what extent they felt like they were in an environment generated by a computer.

Firstly, for the responses gained from question fourteen, by far the largest response from students was the ‘agree’ option. This response occurred in 43.48 percent of all cases. After the ‘agree’ option, the second most selected option was
‘strongly agree’, with 39.13 percent of all responses. When looking at these responses, it represents over 82 percent of all participants completing the laboratory believing the equipment used to gather data was real. Why this is important to know is that for students to believe in the accuracy and validity of the data being generated, they must also believe the equipment being used to generate said data is also real. This is also important information due to the fact that the equipment was never shown to students, only the outputs of the system, which were presented online in real time. By having no real time output of a video feed or any web camera type system, students were required to either trust their instructions that the equipment was real, or to be able to establish based off of the outputs that the data was not being generated through a simulation, and that real equipment was being utilised. This was done without having to prove to the students that the data was gathered from real equipment.

Of the remaining responses, 8.70 percent of responses selected the ‘neutral’ option, while ‘disagree’ and ‘strongly disagree’ had 4.35 percent of the students’ responses each. When comparing 4.35 percent of responses to the 39.12 and 43.48 percent gained in the ‘strongly agree’ and ‘agree’ categories, it can be noted just how large a percentage of students believed that real equipment was being used to generate the data in real time.

What is interesting about this, is when asking students if they felt like they were in an environment created by a computer, ideally there would be a very strong tendency to select the ‘disagree’ option, however this was not observed.
When looking at the responses for question fifteen, 50 percent of all responses were either neutral or agree, with these being the most selected options. After this was the ‘disagree’ option, with just over 20 percent of all responses, followed by strongly disagree and strongly agree, with 16.67 and 12.5 percent of the responses respectively.

The results gathered from this survey indicate that this question received the response that it did due to students looking at the computer environment created by the web interface, instead of a virtual environment. This data can be interpreted to show that students understood that the hardware was real, however a computer was being used to display the outputs of the system to the users.

Figure 44 shows the information from these two questions being displayed on a single figure, where the strength of question fourteen can be observed.

Question five of this survey is also important to observe at this stage. It asked students to respond on a Likert scale regarding the extent that they agreed with the statement ‘I felt like I was completing the laboratory using real equipment’. This question differed only slightly from question fourteen, which was looking at how much students agreed with the statement ‘I felt like the equipment being used to gather data was real’.

Question five gained by far the largest amount of responses selecting the ‘agree’ option, at 46.67 percent. After this was the ‘disagree’ and ‘neutral’ option, at 23.33 percent and 20.00 percent respectively. After this was strongly agree, at 6.67 percent and strongly disagree, at 3.33 percent. This shows again that the
participants in the majority believed the data being generated was done using real equipment instead of simulated devices. The combination of these responses on a single axis in Figure 50. This figure shows by far the largest number of responses is gained from students agreeing with statements pertaining to the equipment being used to gather the data was real.

While it is true that the equipment was real, it should again be emphasised that this was never proven to the students, and therefore students had to both believe in the validity of the data and the validity of the equipment based only on the outputs of the system.

Finally, it was decided to observe if students felt any kind of presence while completing the laboratory. The responses for question fifteen can be used in this instance to observe that students felt although they were completing the laboratory in an environment created by a computer, indicating a lack of presence. Question sixteen of this survey also looked into this, asking students to give their opinion on to what extent they agreed with the statement ‘I felt like I was physically in the environment logging data’. This response was by far the most neutral, with responses between agree, neutral and disagree having minimal variance, with a slight drop off over the strongly agree and strongly disagree options. This is displayed in Figure 51, and it can be observed from this that there was very little or a very neutral presence felt by students completing this laboratory.

While a lack of a web cam did not suspend students’ belief on the accuracy and the reliability of the data, the lack of presence in the laboratory likely would
have been increased with this addition. It is therefore a future change that will be implemented, and any increase in presence felt can be documented and compared to the data shown in Figure 51.

10.4. Improvements

When looking at the design of this remote laboratory, there are some marked improvements that could be made to ideally improve the educational process for the students as they observe the data presented to them in the process of completing this laboratory. While some improvements have already been mentioned in this chapter, they will be further iterated at this point.

The improvements to the laboratory system will be discussed in two separate sections, those being supplemental information for the solar inverter, as well as additional systems that could be incorporated into the remote laboratory to increase the amount of information students gain access to while accessing the laboratory.

The supplementary improvements are described below. Feedback for these sections would add more information to the already existing solar inverter outputs. Many of these systems aim to improve the feeling of presence felt by students, creating a more immersive experience. Others aim to increase the amount of solar data given to the students, such that they can have a better informed opinion on the trends they observe in the solar data received.

Feedback from presenting the build of the laboratory was given, indicating a concern over the lack of a web camera. An idea was proposed that instead of having a web camera point at equipment, to instead point it to the sky, allowing
the user to see the current weather affecting the solar panels, and therefore see how this affected the output of the solar inverter. This would provide two benefits, the first being that students accessing the laboratory from a location outside of Australia could quickly know what weather was occurring, as well as a rough estimate of the time of day. This would mean a student accessing the laboratory during low sunlight hours will know the zero output is due to this, and not a fault of the equipment.

Code for this improvement was developed, however it was never implemented. The system developed was intended to display only the solar panels. An iteration that instead showed the sky would be much easier to implement as things like having a power source and weather proofing the entire device would not be an issue as all that would be needed would be a room with a window and power outlet. This makes the system much easier to maintain than one that needed to be kept outdoors. Accessing the hardware would also be much easier, as roof access would not be required.

In addition to having more information displayed to the user, this system could possibly improve the presence felt by the students accessing the laboratory. This would need to be verified in a future study with the camera installed and operational.

When looking at more information to give to the students regarding the solar outputs, it was expressed by some students and academics that more data about the current weather conditions would assist in further understanding the solar power outputs. An idea presented was to provide weather and temperature
information of the solar inverter, updated live as with the inverter outputs. This improvement could be handled in one of two separate ways. They will be discussed below.

For weather information, there is already readily available information online of the current temperature and weather, however their update period is not nearly as regular as the inverter, and therefore would likely appear irrelevant. This solution however would require no new hardware to be implemented into the system. It could be handled simply by linking to websites such as the Bureau of Meteorology, a website responsible for both weather forecasts and weather updates. This solution would provide current temperature, rain levels, and wind speed and direction, updated every half an hour. The issue with this solution is also that the closest weather location is 8.4km away from the physical solar panels.

The solution to link to this data would be relatively simple to implement, but would be impossible to control or modify. Due to this, an alternative solution could be developed. This solution involves purchasing weather monitoring software and monitoring the weather levels with this.

One of the advantages to this type of system is that since the laboratory was set up to be easily modifiable to any new system, all required programming would be modifiable from what exists previously, with only the batch file needing updating.

There exists functionality to encode data being sent to the server with information informing the server of what source it came from. Currently all data
that would allow for this functionality is stripped from all received data as all that is expected is solar data, however the functionality could easily be re-added. As with both solutions, the website would need to be updated to incorporate this additional information.

It was discussed previously that improvements to the renewable energy remote laboratory could incorporate adding in entirely new systems. One such system is the addition of a wind turbine, and the outputs generated by the wind inverter. This would allow students to analyse multiple different renewable energy system outputs in a single laboratory, as well as observe the outputs of these systems compared to each other.

Such a system could incorporate the additional wind speed information discussed previously in order to improve the amount of information given to the students, and to implement a reference point for the amount of energy generated by such a system. Currently the time of day the solar data is collected is given to the students to use as a reference point, as this allows students to guess what the solar radiation levels are, however with wind power this would not matter as much as wind speed, so this information too would need to be incorporated into the laboratory. This would allow for students to more accurately estimate expected power output when comparing it to the current wind levels. Due to this, the option of taking wind speed from the Bureau of Meteorology would not be a viable solution, as these outputs are only updated every half an hour.

Finally, the sample size of this experiment was very limited in some sections. Survey responses from students were very low in number, regardless of how many
times students accessed the laboratory. It should be noted therefore that for these sections a larger sample size would have led to more confidence in these results. Another improvement of a larger response rate would have been that different geographic and cultural set of students being polled could theoretically have affected the results obtained. An improvement therefore would be to run the experiment over a substantially larger population, or to establish a different method of gathering data, perhaps through interviews or by analysing students’ practical reports. This was achieved in some sections, such as using google analytics to witness student behaviour, but could be improved during future iterations.

10.5. Engineers Australia education requirements

At this point the Engineers Australia competencies will be discussed, specifically those available in the program accreditation section. This accreditation normally is completed on a five year cycle, and covers the material required by higher institutes to be able to have an accredited engineering program. Because the program does not take into consideration a major, the assessment must be general for all engineering degrees. This discussion will primarily focus on the Australian engineering competencies, but will also discuss the European and United States requirements for undergraduate engineering. The discussion will focus on the requirements of undergraduate engineering, and which competencies this laboratory will assist students in demonstrating, as well as a general discussion on the implementation of this laboratory in order to assist with the Engineers Australia engineering course requirements.
This laboratory forces students to display a conceptual understanding of the way in which electricity is generated from a renewable energy system. Without it, things like joules, watts and their relationship will not be understood, however exposure to these elements assists the undergraduate engineer with demonstrating this competency. They must also understand and be able to interpret the graphical data as it displayed on an updating axis, and to understand the mathematics behind such a display, how the time axis changes and what the changing values represent. In addition to this, the experience of being exposed to a functional system instead of a model of a system forces students to interpreted data that is not displayed in a perfect format. They gain exposure to the noise that a system would experience, to the perfections real world systems incorporate and forces students to imagine possible solutions. In addition to this it is a tool that is available remotely, meaning the ways students interact with it is fundamentally different from a traditional laboratory experience, as things like access time and access medium can be different, changing the ways educational institutions can use it as an education tool. The laboratory also requires students to gain exposure to the outputs of a renewable energy system, a resource some of the engineers will be utilising in their professional career.

Fluency in engineering systems, specifically an understanding of the expected outputs of the systems students will be using in their professional career is a recognised competency that Engineers Australia requires all undergraduate students to be able to display. This competency is further described in section 2.2 of the Engineers Australia competency guidelines, stating students must have ‘fluent application of engineering techniques, tools and resources.’ This
laboratories assistance in this competency comes in the form of showing them real outputs from a renewable energy system instead of simulated outputs. By changing the viewing experience from what could be a simulated curve, or just daily outputs, students can view this data as very erratic, often changing by very large percentages within the expected output size.

Within this competency (Program-Accreditation Engineers Australia, 2017) there are two sections that are particularly relevant to this laboratory, those being subsection d, which states that competent engineers are capable of applying ‘a wide range of engineering tools for analysis, simulation, visualisation, synthesis and design, including assessing the accuracy and limitations of such tools, and validation of their results’, and subsection G, which requires students to be capable of analysing ‘sources of error in applied models and experiments; eliminates, minimises or compensates for such errors; quantifies significance of errors to any conclusions drawn.’

One of the important lessons that undergraduate students hopefully learn from completing this laboratory is the unpredictability of renewable energy when analysed over small time periods, and while over longer time periods, specific trends can be analysed, this is no longer the case as time period becomes significantly smaller. The fact that the laboratory assists in visualisation of the outputs in a solar renewable energy system also links to this competency. In this was subsection d of the engineering Australia competency guideline is addressed.

The laboratory displays outputted data, but also allows students to view logs with only a single average value. All of these values are simply the average value,
but expecting this value to remain consistent will give many errors. By exposing students to this system, they should be able to accurately visualise the outputs of one they implement, and account for any error within such a system. In this way, students are exposed to a system that has error and that does not have a consistent output. They must be able to analyse this data regardless, and to know the significance of these numbers before any conclusion about the system can be made. This shows the subsection g competency must be addressed by students analysing this laboratory.

When observing outputs of a system, especially one as unpredictable as a renewable energy system, students must be able to properly assess the reliability of such a system, as well as its authenticity. To assume a model that provides a single average daily output will be accurate at all stages of solar output would not be feasible. This is a relevant competency to be able to display, as in section 3.4, pertaining to the ‘Professional use and management of information’, students are expected to ‘critically assesses the accuracy, reliability and authenticity of information.’

Engineers Australia requires students to display specific competencies for an engineering graduate degree, however there are also guidelines required for the delivery of the engineering degree. Specifically, Engineers Australia requires all courses have an on campus component to their undergraduate educational processes, meaning that students studying engineering remotely are still required to attend their university for what amounts to a week worth of on campus work per trimester. While this on campus requirement can be used to run practical
components, with the addition of remote laboratories, this time could instead be spent working face to face with the lecturer in a tutorial or seminar environment covering theory or allowing question and answer time. It would also allow students more time to raise concerns about their studies. By allowing information such as that displayed in this laboratory to be available to remote linked students, it removes a barrier of studying remotely, and if remote laboratories were to be further adopted would allow the one contact week to be available for other activities if required. This would also allow unit co-ordinators an extra degree of flexibility in their planning of the undergraduate engineering course.

With the study of engineering being a global recognised discipline, accreditation bodies outside of Australia must too exist. These accreditation bodies each with their own unique set of standards for what constitutes a professional engineer, and what criteria a degree must uphold in order to gain accreditation. The two accreditation bodies that will be discussed below are the Engineering Network for Accreditation of Engineering Education (ENAAE), who handle European undergraduate engineering accreditation through what they describe as the EUR-ACE system (EUR-ACE® Framework Standards and Guidelines, 2017), and the Accreditation Board for Engineering and Technology (ABET), who handle undergraduate engineering degrees in the United States (ABET CRITERIA FOR ACCREDITING ENGINEERING PROGRAMS, 2017).

The EUR-ACE Framework Standards and Guidelines Mar 2015 document section 2.3.1 Programme Outcomes for Bachelor Degree Programmes (EUR-ACE® Framework Standards and Guidelines, 2017) specifies required skills for
undergraduate engineers. Much like the EA guidelines, the document provides competencies that must be displayed. Specifically, undergraduate engineers must be capable of completing a degree in which ‘the learning process should enable Bachelor Degree graduates to demonstrate: laboratory/workshop skills and ability to design and conduct experimental investigations, interpret data and draw conclusions in their field of study.’ This ability to interpret raw data is required while completing this remote laboratory. In addition to this, ‘the learning process should enable Bachelor Degree graduates to demonstrate: ability to gather and interpret relevant data and handle complexity within their field of study’

Finally, the ABET Criteria for Accrediting Engineering Programs document (ABET CRITERIA FOR ACCREDITING ENGINEERING PROGRAMS, 2017) requires that for undergraduate engineering degrees, ‘modern tools, equipment, computing resources, and laboratories appropriate to the program must be available, accessible, and systematically maintained and upgraded to enable students to attain the student outcomes and to support program needs’, with the masters course in electrical engineering requiring exposure to tools ‘necessary to analyse and design complex electrical and electronic devices’
11. Conclusion

This research aimed to answer three unique questions, those being how students would approach learning on a remotely accessible renewable energy laboratory that provided them access to real time visualisation of an active renewable energy system, how students would interpret realism in their education without the use of a web camera for this remote laboratory and the perceived learning objective of a laboratory presented to students in the method described in this text. To assist in answering this question, the design, build and implementation of this laboratory was also analysed.

The build followed specific design goals, such as having the laboratory require no software to be previously installed onto the users system, as well as allowing for any device access to a standard user interface of the laboratory. This ensured both a consistent user experience as well as a more reliable experience. It also ensured that the users’ choice of access device had very little bearing over their experience, as all devices and operating systems could access the laboratory. The web interface was set up so that it would not require a large amount of bandwidth to allow for users on limited data or limited download speed equivalent access. The implications of this design is also that the data being displayed would be able to be updated in real time, but still be accessible by every student from any location connected to the internet.

The design of the laboratory allowed for both a modular system that was able to be easily modified to work with a wide range of systems by isolating system specific code and calling them separately. It connected to the solar inverter via
USB inputs, meaning that extra peripherals could easily be added, allowing for the expansion of the system to implement extra functionality. The laboratory architecture also ensured that when connecting the device in-between the current communication channels, the solar inverter systems functionality would not be inversely affected, meaning that all other work using the solar inverter would remain unaffected by the system.

The testing was completed using multiple different avenues to collect all required research data, including not only students’ experience in the laboratory via the use of a survey, but also students’ access habits and behaviours via Google analytics. The survey allowed for both short answer style responses as well as responses from a Likert scale, giving both numerical data as well as written responses, but had a low number of student responses at only 34.

A study on students’ willingness to adopt a remote education style was conducted, showing that students were willing to adopt remote education, and even replace on campus requirements for the remote education equivalent. This study was done to ensure the primarily on campus research participants would be willing to adopt the educational style required for this laboratory, that being interacting with a laboratory in a remote format.

Looking at the specific research question, and research goals, when analysing the behaviour of students in the laboratory, a large number of students accessed the remote laboratory the day it was made available to them, however there was a large drop off of access numbers after this date, having a spike in access numbers when students were sent emails with additional laboratory information. This was
to be expected, however was backed up by the data. The number of users accessing via Macintosh devices was significantly larger than initially hypothesised, with just under half the devices used being Macintosh devices. This was eleven percent larger than the next access device, this being windows devices. This data supports the previously completed research on students’ preferred mobile device usage to access additional resources, finding the iPhone and iPad ranking higher than all other devices. The choice of web browser was largely Google Chrome, with almost two thirds of users accessing via this operating system. This was followed by Firefox, with a little under a third of all users using this web browser.

Finally, the number of users being either new visitors or returning visitors was analysed, with 73% of all users being new visitors. This shows almost three quarters of users accessing the laboratory only a single time. This was to be expected, as the laboratory system was implemented as a way to introduce students to the renewable energy system, and had little functionality requiring multiple visits. All logged data could be downloaded, so even long term studies could be conducted after a single visit.

When analysing the students’ responses to their experience in the laboratory, the student perception of primary learning objective was analysed. Short answer and Likert scale responses were used to gather this data. From written responses, the expected responses would be laboratory specific. This was supported by the data gathered, with the majority of responses saying the primary learning objective was to study power and photovoltaic cells. Other responses focused on
the perception that the laboratory focused on real time visualisation of outputs, another lab specific response. When gathering responses form a Likert scale, the topics chosen to analyse laboratory focus were used to determine the perceived learning focus of the students. Signal analysis gathered the largest number of responses, followed very closely by general engineering principals.

These numbers differ from the research done comparing the perceived learning objective of different access modes completed so far, further enforcing the concept that the medium used to present students with practical content can affect the way in which they approach learning the material. With this new method of delivering content, there is again a different focus by students, meaning that if a specific learning objective is required, the medium used to deliver content should be analysed to determine if it can affect the student learning experience.

The final analysis was to observe the users perception of reality of the equipment and results in the remote laboratory. This section separated both the validity of the data and the realism of the equipment into two separate categories. When being surveyed on the perception of validity of the data, a vast majority of responses indicated that students believed the data they were observing was in fact real. This was also mirrored in the responses of perceived realism of equipment, with students also believing the data was gathered from a real system. This is despite the fact that no web camera or other video feed was used, showing that this belief in realism was not due to students requiring a live feed of the equipment.
This belief in realism did not translate to a strong feeling of presence however, as the overall feeling of presence in the laboratory was very neutral. This shows that although students can believe the equipment they are working on is real, and the data they gained from the equipment is likewise real, their perception of presence in the laboratory was not affected by either of these outcomes.

The laboratory presented in this research had the benefits of clearly displaying information to the user, however there are some specific improvements that will be implemented in future uses of this laboratory. The use of solar power as the only output displayed could be enhanced by the addition of other energy generation systems, specifically a wind powered inverter. Not only would the addition of this extra system prove the modularity of the hardware and software combination, but it would further expose students to a wider range of renewable energy systems and their specific outputs. The implementation of this system would also allow for students to analyse the different outputs of wind at different wind speeds and hours of the day. This would hopefully improve the laboratory experience.

The result of this research support the belief that while a live video feed is not required to increase students’ belief in validity of results, or validity of equipment being used, it will still have a direct influence on the degree of presence being felt. Although the laboratory did not need a web camera to prove the reliability of the data presented to students, there was a noticeable lack of presence felt by those students observing the solar outputs. This lack of presence
could ideally be solved by introducing a video feed. Multiple different locations have been considered, including a video feed of the sky over the solar panels, a video feed of the solar inverter or a video feed of the solar panels themselves. Each would be carefully considered before implementing one, or possibly multiple of these solutions.

For future iterations of this laboratory, increasing the level of interactivity in the laboratory would be a useful addition with the intention of increasing student engagement. This could be done either through the use of increased outputs of the system such as a video feed, however could also be achieved by having the user be allowed to control specific hardware via the use of inputs. This could be something as simple as a camera where the user can control pan and tilt, solving the issue of needing two web cameras to point at the solar panels or the sky. While this addition would not change the information being presented to the user, it would ideally increase interactivity with the laboratory. A potential issue arising from this would be having multiple people trying to control the hardware, however this could be solved with a queuing system for inputs, where a movement can only be made every few seconds, and a user’s input is queued into the system. While requiring further refinement, this solution should still allow multiple users access to the laboratory simultaneously, while still having the ability to interact with the hardware outputs.

Another possible addition to the laboratory would be current solar levels taken from the Bureau of Meteorology, or current temperature levels as measured at the location of the solar panels. This additional information could be
used to further increase the information available for analysis, but also to show students the effect of fluctuating weather levels on the power generated.

When dealing with improvements to the research method, further care would be taken to ensure users understood all functionality of the laboratory, as well as information such as how to convert a CSV (comma-separated values) file to an excel document. While this was assumed to be knowledge students would have, when opening the logged files for the first time this was not immediately apparent the file format required, and some students therefore did not properly view and therefore gain exposure to the logged laboratory data. This could be further improved by updating the laboratory instructions.

These instructions could also have benefited from easier circulation to the students. They were discussed in lectures and then presented as an online resource, but sending emails to all students with instructions for laboratory access and benefits of accessing the laboratory would likely have increased participation.

While the laboratory was not a mandatory assessment in any of the classes it was implemented, if there was an assessed task requiring laboratory interaction the research could have been expanded into areas dealing with assessed material, as well as student engagement and motivation to complete the laboratory while being assessed, as well as having a direct mark associated with the laboratory. This information would have assisted in further increasing the pedagogical body of knowledge, but will require being researched further in the future.

With the summary of the results gathered in mind, specific implications of this research can be gathered. Firstly, by knowing that students’ approach the learning
medium differently that other remote laboratories, the learning experience of university level students can be modified to best reflect the desired learning outcomes of the specific subject. By knowing how a student will approach learning on a specific medium, it is possible to modify the learning experience to be able to show students not only new information, but to also know how students will engage and interact with this new information. Such an ability could therefore be used in the design and implementation of laboratories such that they are used to further enhance the learning experience of the students. By analysing not only laboratory content, but the medium used for content delivery, a practical session and its specific desired learning objectives can be created. Knowing which learning objective a student focuses on with each practical delivery medium could be used to further guide the learning outcomes and the learning experiences of these university level students.
12. Appendix 1

Survey and access appendix

12.1. Accessing laboratory

12.1.1. Instructions given to students

Accessing Renewable Energy Remote Laboratory

Step 1:

Access Deakin VPN through Junos Pulse.

This step is only required for users who are not using a Deakin work station. If you are using a Deakin work station, go to step 2.

Information on how to connect to the Deakin VPN can be found at the following address:


This is a required step if not currently working on a Deakin work station.

For a video guide of how to connect to the Deakin VPN, click on the following link:

https://support.deakin.edu.au/kb_view.do?sysparm_article=KB0010496

Please note the video uses Windows 8.1

Step 2:
Access the Remote laboratory

To access the remote laboratory, type the following address into your web browsers address bar:

http://10.116.48.68/

The lab is now accessible.

If there are any issues, questions or queries, please use the following contact email:

liam.lyons@deakin.edu.au
Dear students studying CLASS

As part of CLASS you were invited to complete an online laboratory allowing you to view the live outputs of a renewable energy system in real time. This laboratory was available after using the following link:

LINK

After completing this laboratory, you are invited to take part in a research project, by Mr. Liam Lyons PhD student, School of Engineering. The project seeks your views for the purpose of improving the students’ learning experience. The project will use the data collected to evaluate and study the experience of students completing remote laboratories using real world inputs.

The survey is available by using the following link:

LINK

The information will be used to understand the way students interact with remote laboratories, as well as the learning outcomes associated with remote laboratories.

Participating in the study involves completing an online questionnaire, which will take approximately 10 minutes. You will be asked to respond by ticking response options or by filling in text responses. To participate in this research project and online survey, you must be 18 years of age or older.

All data is anonymous and individual participants will not be able to be identified in any of the data collected.
The data will be compiled in the form of a written report (available by email request to the Chief Investigators) that will be used to assist in the development of curriculum to improve students’ experiences completing online remote laboratories. The findings from this project may be published in academic journals and/or presented at conferences.

Please complete and submit the online survey as per the instructions below. Your participation is voluntary, and you have the right to withdraw from the study at any time, even after you have started answering the questionnaire. However, once your results are submitted, your survey cannot be withdrawn, as the responses cannot be linked back to the individual.

Your decision whether or not to take part will not affect your marks in any way or your relationship with any staff member at Deakin University. Your participation will contribute to the improvement of future engineering education curriculum delivery.

Thank you for your willingness to participate in this research project by completing the online survey. If you have any questions regarding the project at any stage, or wish for an emailed copy of the final project report, please contact the Chief investigators:

Assoc. Prof. Matthew Joordens (School of Engineering - matthew.joordens@deakin.edu.au), and/or Mr. Mr. Liam Lyons (School of Engineering - liaml@deakin.edu.au)
Approval to undertake this research project has been given by the Human Ethics Advisory Group, Faculty of Science and Technology, Deakin University.

**Complaints:** If you have any complaints about any aspect of the project, the way it is being conducted or and questions about your rights as a research participant, then you may contact:

The Manager, Ethics and Biosafety, Deakin University, 221 Burwood Highway, Burwood Victoria 3125, Telephone: 92517129, [research-ethics@deakin.edu.au](mailto:research-ethics@deakin.edu.au)

Please quote project number: **NUMBER**

**HOW TO ACCESS THE ONLINE SURVEY**

Please use the link and user code below to access the survey. By completing and submitting the survey you indicate that you have read the Plain Language Statement and give your consent for your responses to be used in this research.

Your participation is important for the success of this research project.

**SURVEY USER CODE:** Students’ perceptions of real world remote laboratories

**CLICK HERE VIA WEB LINK TO ACCESS THE ONLINE SURVEY:**

**LINK**

The survey will be available until **DATE**.

THANK YOU FOR YOUR WILLINGNESS TO PARTICIPATE.

Yours sincerely

**Mr. Liam Lyons**

**Higher Degree by Research**
12.1.3. Proposed Survey questions

Thank you for participating in our survey. Your feedback is important.

Q1
To what extent do you agree with the following statements?
I *found the remote laboratory intellectually stimulating*
- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
Why/Why not?

Q2
What do you feel the primary learning objective of the remote laboratory was?

Q3
To what extent do you agree with the following statements?
*I felt like I was completing a laboratory using real equipment*
- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
Q4
How much did you feel the remote laboratory focused on the following areas:

**Hardware being used**
- Very little focus
- Little focus
- Average focus
- Large amount of focus
- Specialised focus

**Theory of specific lab**
- Very little focus
- Little focus
- Average focus
- Large amount of focus
- Specialised focus

**Calibration principals**
- Very little focus
- Little focus
- Average focus
- Large amount of focus
- Specialised focus

**Practical links to theory**
- Very little focus
- Little focus
- Average focus
- Large amount of focus
- Specialised focus

**Signal analysis**
- Very little focus
- Little focus
- Average focus
- Large amount of focus
- Specialised focus

**General Engineering Principals**
- Very little focus
- Little focus
- Average focus
- Large amount of focus
- Specialised focus

**Other (please specify)**
- Very little focus
- Little focus
- Average focus
- Large amount of focus
- Specialised focus
Q5
To what extent do you agree with the following statements?

I felt like the data being generated was real
- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

I felt like the equipment being used to gather data was real
- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

I felt like I was in an environment created by a computer
- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

I felt like I was physically in the environment logging data
- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

Q6
To what extent do you agree with the following statements?

The remote laboratory was helpful for understanding the topics covered in this unit
- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

Why/Why not
Q7
To what extent do you agree with the following statements?
*The remote laboratory could be improved*
- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
Why/Why not

Q8
Do you have any additional comments about the remote laboratory?
Additional comments
Appendix 2
Raw data appendix

12.2. Student responses to survey questions

12.2.1. Student response to survey question 1

<table>
<thead>
<tr>
<th>Q1</th>
<th>I found the remote laboratory intellectually stimulating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly disagree</td>
<td>11.76470588</td>
</tr>
<tr>
<td>Disagree</td>
<td>8.823529412</td>
</tr>
<tr>
<td>Neutral</td>
<td>20.58823529</td>
</tr>
<tr>
<td>Agree</td>
<td>44.11764706</td>
</tr>
<tr>
<td>Strongly Agree</td>
<td>14.70588235</td>
</tr>
</tbody>
</table>

12.2.2. Student response to survey question 4

<table>
<thead>
<tr>
<th>Q4</th>
<th>I felt like I was completing a computer simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly disagree</td>
<td>12.90322581</td>
</tr>
<tr>
<td>Disagree</td>
<td>35.48387097</td>
</tr>
<tr>
<td>Neutral</td>
<td>22.58064516</td>
</tr>
<tr>
<td>Agree</td>
<td>22.58064516</td>
</tr>
<tr>
<td>Strongly Agree</td>
<td>6.451612903</td>
</tr>
</tbody>
</table>
### 12.2.3. Student response to survey question 5

<table>
<thead>
<tr>
<th>Q5</th>
<th>I felt like I was completing a laboratory using real equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly disagree</td>
<td>3.333333333</td>
</tr>
<tr>
<td>Disagree</td>
<td>23.33333333</td>
</tr>
<tr>
<td>Neutral</td>
<td>20</td>
</tr>
<tr>
<td>Agree</td>
<td>46.66666667</td>
</tr>
<tr>
<td>Strongly Agree</td>
<td>6.66666667</td>
</tr>
</tbody>
</table>

### 12.2.4. Student response to survey question 13

<table>
<thead>
<tr>
<th>Q13</th>
<th>I felt like the data being generated was real</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly disagree</td>
<td>4.166666667</td>
</tr>
<tr>
<td>Disagree</td>
<td>4.166666667</td>
</tr>
<tr>
<td>Neutral</td>
<td>4.166666667</td>
</tr>
<tr>
<td>Agree</td>
<td>50</td>
</tr>
<tr>
<td>Strongly Agree</td>
<td>37.5</td>
</tr>
</tbody>
</table>
### 12.2.5. Student response to survey question 14

<table>
<thead>
<tr>
<th>Q14</th>
<th>I felt like the equipment being used to gather data was real</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly disagree</td>
<td>4.347826087</td>
</tr>
<tr>
<td>Disagree</td>
<td>4.347826087</td>
</tr>
<tr>
<td>Neutral</td>
<td>8.695652174</td>
</tr>
<tr>
<td>Agree</td>
<td>43.47826087</td>
</tr>
<tr>
<td>Strongly Agree</td>
<td>39.13043478</td>
</tr>
</tbody>
</table>

### 12.2.6. Student response to survey question 15

<table>
<thead>
<tr>
<th>Q15</th>
<th>I felt like I was in an environment created by a computer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly disagree</td>
<td>16.666666667</td>
</tr>
<tr>
<td>Disagree</td>
<td>20.83333333</td>
</tr>
<tr>
<td>Neutral</td>
<td>25</td>
</tr>
<tr>
<td>Agree</td>
<td>25</td>
</tr>
<tr>
<td>Strongly Agree</td>
<td>12.5</td>
</tr>
</tbody>
</table>
### 12.2.7. Student response to survey question 16

<table>
<thead>
<tr>
<th>Q16</th>
<th>I felt like I was physically in the environment logging data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Strongly disagree</td>
<td>12.5</td>
</tr>
<tr>
<td>Disagree</td>
<td>25</td>
</tr>
<tr>
<td>Neutral</td>
<td>25</td>
</tr>
<tr>
<td>Agree</td>
<td>25</td>
</tr>
<tr>
<td>Strongly Agree</td>
<td>12.5</td>
</tr>
</tbody>
</table>

### 12.2.8. Student response to survey question 17

<table>
<thead>
<tr>
<th>Q17</th>
<th>The remote laboratory was helpful for understanding the topics covered in this unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Strongly disagree</td>
<td>8.695652174</td>
</tr>
<tr>
<td>Disagree</td>
<td>21.73913043</td>
</tr>
<tr>
<td>Neutral</td>
<td>21.73913043</td>
</tr>
<tr>
<td>Agree</td>
<td>30.43478261</td>
</tr>
<tr>
<td>Strongly Agree</td>
<td>17.39130435</td>
</tr>
</tbody>
</table>
### 12.2.9. Student comparison survey question 4 and question 13

<table>
<thead>
<tr>
<th>Q4 Q13 comparison</th>
<th>Computer Sim</th>
<th>Real</th>
<th>Weighted combine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Answer</td>
<td>Q4</td>
<td>Q13</td>
<td></td>
</tr>
<tr>
<td>Strongly disagree (0)</td>
<td>12.90322581</td>
<td>4.16666666</td>
<td>5.454545</td>
</tr>
<tr>
<td>Disagree(1)</td>
<td>35.48387097</td>
<td>4.16666666</td>
<td>14.54545</td>
</tr>
<tr>
<td>Neutral(2)</td>
<td>22.58064516</td>
<td>4.16666666</td>
<td>14.54545</td>
</tr>
<tr>
<td>Agree (3)</td>
<td>22.58064516</td>
<td>50</td>
<td>41.81818</td>
</tr>
<tr>
<td>Strongly Agree (4)</td>
<td>6.451612903</td>
<td>37.5</td>
<td>23.63636</td>
</tr>
<tr>
<td>Average response</td>
<td>1.741935484</td>
<td>3.125</td>
<td></td>
</tr>
<tr>
<td>Percentage value</td>
<td>35.7912179</td>
<td>64.20878</td>
<td>100</td>
</tr>
<tr>
<td>Believed data was computer simulated</td>
<td>35.7912179</td>
<td>64.20878</td>
<td></td>
</tr>
<tr>
<td>Q14 Q15 comparison</td>
<td>Real equip</td>
<td>Computer sim</td>
<td>Weighted combine</td>
</tr>
<tr>
<td>--------------------</td>
<td>-----------</td>
<td>-------------</td>
<td>------------------</td>
</tr>
<tr>
<td>Answer</td>
<td>Q14</td>
<td>Q15</td>
<td></td>
</tr>
<tr>
<td>Strongly disagree (0)</td>
<td>4.347826087</td>
<td>16.666666667</td>
<td>8.510638</td>
</tr>
<tr>
<td>Disagree(1)</td>
<td>4.347826087</td>
<td>20.833333333</td>
<td>14.89362</td>
</tr>
<tr>
<td>Neutral(2)</td>
<td>8.695652174</td>
<td>25</td>
<td>17.02128</td>
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<tr>
<td>Agree (3)</td>
<td>43.47826087</td>
<td>25</td>
<td>31.91489</td>
</tr>
<tr>
<td>Strongly Agree (4)</td>
<td>39.13043478</td>
<td>12.5</td>
<td>27.65957</td>
</tr>
<tr>
<td>Average response</td>
<td>3.086956522</td>
<td>1.958333333</td>
<td></td>
</tr>
<tr>
<td>Percentage value</td>
<td>61.18491921</td>
<td>38.81508</td>
<td>100</td>
</tr>
<tr>
<td>Believed equipment was real</td>
<td>35.7912179</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Believed equipment was computer generated</td>
<td></td>
<td>64.20878</td>
<td></td>
</tr>
</tbody>
</table>
### 12.2.11. Student weighted output when observing learning focus

<table>
<thead>
<tr>
<th>Category</th>
<th>Weighted</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware being used</td>
<td>182.4</td>
<td>15.55252</td>
</tr>
<tr>
<td>Theory of specific lab</td>
<td>177.6</td>
<td>15.14325</td>
</tr>
<tr>
<td>Calibration principals</td>
<td>158.4</td>
<td>13.50614</td>
</tr>
<tr>
<td>Practical links to theory</td>
<td>153.6</td>
<td>13.09686</td>
</tr>
<tr>
<td>Signal analysis</td>
<td>216</td>
<td>18.41746</td>
</tr>
<tr>
<td>General Engineering Principals</td>
<td>201.6</td>
<td>17.18963</td>
</tr>
<tr>
<td>Misc/Other</td>
<td>83.2</td>
<td>7.094134</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1172.8</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>
### 12.3. Google Analytics data collected

#### 12.3.1. Example time period

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/07/2016</td>
<td>26/09/2016</td>
</tr>
</tbody>
</table>

#### 12.3.2. Raw data collected from Google analytics during this time period

<table>
<thead>
<tr>
<th>New/Returning</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>New Visitor</td>
<td>110</td>
<td>73.30%</td>
</tr>
<tr>
<td>Returning Visitor</td>
<td>40</td>
<td>26.70%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Browser</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Chrome</td>
<td>96</td>
<td>64%</td>
</tr>
<tr>
<td>Firefox</td>
<td>43</td>
<td>28.67%</td>
</tr>
<tr>
<td>Safari</td>
<td>6</td>
<td>4%</td>
</tr>
<tr>
<td>Internet explorer</td>
<td>5</td>
<td>3.33%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operating System</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Macintosh</td>
<td>73</td>
<td>48.67%</td>
</tr>
<tr>
<td>Windows</td>
<td>57</td>
<td>38%</td>
</tr>
<tr>
<td>Linnux</td>
<td>17</td>
<td>11.33%</td>
</tr>
<tr>
<td>Android</td>
<td>3</td>
<td>2%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Accessing on Mobile</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>OS</td>
<td>Android</td>
<td>(100%)</td>
</tr>
<tr>
<td>Extra information</td>
<td></td>
<td>Description</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>-------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>Bounce Rate</td>
<td>62%</td>
<td>People who only viewed front page</td>
</tr>
<tr>
<td>Page view per session</td>
<td>2.63</td>
<td>Average number of page views per session</td>
</tr>
<tr>
<td>City Located</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not set</td>
<td>76</td>
<td>50.67%</td>
</tr>
<tr>
<td>Geelong</td>
<td>65</td>
<td>43.33%</td>
</tr>
<tr>
<td>other</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Melbourne</td>
<td>2</td>
<td>1.33%</td>
</tr>
</tbody>
</table>
13. Appendix 3

Code

13.1. Communication between devices

13.1.1. PYTHON Data receive from pi and store in database

#!/usr/bin/env python

import MySQLdb
import os
import socket
import time
import datetime
import re

#UDP communication tutorial followed available from the following link:
https://wiki.python.org/moin/UdpCommunication

#Database communication tutorial followed available from the following link:
https://www.digitalocean.com/community/tutorials/how-to-set-up-an-
apache-mysql-and-python-lamp-server-without-frameworks-on-ubuntu-14-
04

print "Start Initialization, database open"

UDP_IP = '10.116.48.68'
UDP_PORT = 3459

BUFFER_SIZE = 20  # Normally 1024, but we want fast response

print "End Initialization"

s = socket.socket(socket.AF_INET, socket.SOCK_DGRAM)

s.bind((UDP_IP, UDP_PORT))

print "End of Part Acception"

while 1:
    day = (time.strftime("%d"))
    month = (time.strftime("%m"))
    year = (time.strftime("%Y"))
    Hour = (time.strftime("%H"))
    Minute = (time.strftime("%M"))
    Second = (time.strftime("%S"))

    # Open database connection
    db = MySQLdb.connect("localhost","USERNAME","PASSWORD","energy")

    # prepare a cursor object using cursor() method
    cursor = db.cursor()

    data,addr=s.recvfrom(1024)  #= #conn.recv(BUFFER_SIZE)

    if not data: time.sleep(1)

    #print data
data = re.sub("[^0-9]", "", data)

try:
    data = int(data)

except ValueError,e:
    print "error"

# print data

#error handling for float>int conversion

try:

    Watts = float(data) / 10

except ValueError,e:

    Watts = 0

print Watts

# conn.send(data)  # echo

# Prepare SQL query to INSERT a record into the database.

query = """INSERT INTO energymade (id, Joules, year, month, day, hour, minute, second, watts) VALUES (NULL,%s,%s,%s,%s,%s,%s,%s,%s)""

# print query

try:

    # Execute the SQL command
cursor.execute(query, (data, year, month, day, Hour, Minute, Second, Watts))

# Commit your changes in the database

db.commit()

except:

    # Rollback in case there is any error

    db.rollback()

# disconnect from server

db.close()

#conn.close()
13.1.2. PYTHON Data sent from pi to store in database

#!/usr/bin/python

print "hello world"

import serial
import threading
import time
import os
import commands
import socket

port1 = serial.Serial ('/dev/ttyUSB0', baudrate = 19200, timeout = 5)
port2 = serial.Serial ('/dev/ttyUSB1', baudrate = 19200, timeout = 5)

port1.open()
port2.open()

com_time = int(time.time()*1000)
log_time = int(time.time()*1000)
oldTime = False
Run = False

def upload(MESSAGE):
    TCP_IP = "IP ADDRESS"
TCP_PORT = PORT NUMBER

s=socket.socket(socket.AF_INET, socket.SOCK_DGRAM)
s.sendto(MESSAGE, (TCP_IP, TCP_PORT))

def myCom():
    global oldTime
    global com_time
    global log_time

    #while True:
    if (log_time + 10000 < int(time.time()*1000)):
        port1.close()
        port2.close()
        j = "BATCH SCRIPT LOCATION"
        time.sleep(.3)
        output = commands.getoutput(j)
        log_time = int(time.time() * 1000)
        time.sleep(.3)
        port1.open()
        port2.open()

        print "Response: " + output

value = output[41:50]
upload(value)

def fromPC():
    global com_time
    time.sleep(1)
    while True:
        if(port1.isOpen()):
            data = port1.read(1)
        if(port2.isOpen()):
            port2.write(data)
        myCom()

def fromINV():
    global com_time
    time.sleep(1)
    while True:
        if(port2.isOpen()):
            data1 = port2.read(1)
        if(port1.isOpen()):
            port1.write(data1)

threadPC = threading.Thread(target=fromPC)
threadINV = threading.Thread(target=fromINV)
threadCOM = threading.Thread(target=myCom)

threadPC.start()
threadINV.start()

#threadCOM.start()
# time.sleep(.3)
13.2. Laboratory graphical data display

13.2.1. HTML Laboratory display live updates code

```html
<!DOCTYPE HTML PUBLIC "-//W3C//DTD HTML 4.01//EN"
"http://www.w3.org/TR/html4/strict.dtd">

<html>
<head>
<meta http-equiv="Content-Type" content="text/html; charset=utf-8">
<title>Solar Inverter Live output</title>

<!-- graphs completed with tutorials from http://www.highcharts.com -->

<!-- 1. Add these JavaScript inclusions in the head of your page -->
<script type="text/javascript" src="http://code.jquery.com/jquery-1.10.1.js"></script>
<script type="text/javascript" src="http://code.highcharts.com/highcharts.js"></script>

<!-- 2. Add the JavaScript to initialize the chart on document ready -->
<script>
var chart; // global

/**

*/
```

* Request data from the server, add it to the graph and set a timeout to request again

*/

```javascript
function requestData() {
  $.ajax({
    url: 'live-server-data.php',
    success: function(point) {
      var series = chart.series[0],
      shift = series.data.length > 10000; // shift if the series is longer than 10000

      // add the point
      chart.series[0].addPoint(eval(point), true, shift);

      // call it again after ten seconds
      setTimeout(requestData, 10000);
    },
    cache: false
  });
}

$(document).ready(function() {
```
Highcharts.setOptions({
  global: {
    useUTC: false
  }
});

chart = new Highcharts.Chart({
  chart: {
    renderTo: 'container',
    defaultSeriesType: 'spline',
    events: {
      load: requestData
    }
  },
}
  ,
  title: {
    text: 'Live Solar data'
  },
  xAxis: {
    type: 'datetime',
    tickPixelInterval: 150,
    maxZoom: 20 * 1000
  },
  yAxis: {
    minPadding: 0.2,
    maxPadding: 0.2,
  }
});
```html
    title: {
        text: 'Joules',
        margin: 80
    },
    series: [{
        name: 'Solar data',
        data: []
    }]
});
</script>

</head>

<body>

<!-- 3. Add the container -->

<div id="container" style="width: 800px; height: 400px; margin: 0 auto"></div>

```
```
<input type="button" value="Live (Watts)" onclick="location='watts.html'" />
<input type="button" value="Last Two Hours" onclick="location='TwoHoursData.html'" />
<input type="button" value="Last Day" onclick="location='LastTwentyfourHours.html'" />

<p>Provide Feedback:</p>
<input type="button" value="Access Survey" onclick="location='survey.html'" />

<p>Download latest data:</p>
<input type="button" value="Last Two Hours" onclick="location='OutputTwoHours.php'" />
<input type="button" value="Last Day" onclick="location='OutputDay.php'" />
<input type="button" value="Last Week" onclick="location='OutputWeek.php'" />

<p>View logged data:</p>
<input type="button" title="Log" value="Access Logs" onclick="location.href='/DataLog/'" />
</body>

</html>
13.2.2. PHP script to collect live updating data from database

```php
<?php

$dbhost = 'localhost:3036';
$dbuser = 'USERNAME';
$dbpass = 'PASSWORD';
$conn = mysql_connect($dbhost, $dbuser, $dbpass);

// data retrieval completed with tutorials from http://www.highcharts.com

if(! $conn )
{
    die('Could not connect: '.mysql_error());
}

$sql = 'SELECT Joules FROM energymade ORDER BY id DESC LIMIT 1';
mysql_select_db('energy');
$retval = mysql_query($sql, $conn);
if(! $retval )
{
    die('Could not get data: '.mysql_error());
}

while($row = mysql_fetch_assoc($retval))
{

}
```
date_default_timezone_set('Australia/Melbourne');

\$x = time() * 1000;

//\$x = time() + (24 * 60 * 60);

/*
 *
 * echo "Joules Measured :\$row['Joules'] \n";
 * "-----------------------------\n";
 * /
 */

//\$x = date_default_timezone_get();

\$ret = array(\$x, (int)\$row['Joules']);

\$echo json_encode(\$ret);

//echo "Fetched data successfully\n";
}

mysql_close(\$conn);

?>
13.2.3. HTLM Laboratory display logged data code (2 hours)

```html
<!DOCTYPE HTML>

<!—graphs completed with tutorials from http://www.highcharts.com -->

<html>
  <head>
    <meta http-equiv="Content-Type" content="text/html; charset=utf-8">
    <title>Solar Inverter Last 2 Hours Data</title>
    <script type="text/javascript" src="http://ajax.googleapis.com/ajax/libs/jquery/1.7.1/jquery.min.js"></script>
  
  <script type="text/javascript">
    $(document).ready(function() {
      var options = {
        chart: {
          renderTo: 'container',
          type: 'spline'
        },
        title: {
          text: 'Solar Inverter (Last 2 Hours) Data',
          x: -20 //center
        },
        xAxis: {
          categories: [],
          title: {text: 'Time (24 hour)', margin: 20}
        }
      }
    });
  </script>
</html>
```
x: -10,
y: 100,
borderWidth: 0
}

series: []

$.getJSON("TwoHourData.php", function(json) {
    options.xAxis.categories = json[0]['data'];
    options.series[0] = json[1];
    chart = new Highcharts.Chart(options);
});

</script>

<script src="http://code.highcharts.com/highcharts.js"></script>

<script src="http://code.highcharts.com/modules/exporting.js"></script>

</head>

<body>
<div id="container" style="width: 800px; height: 400px; margin: 0 auto"></div>

<div style="width: 800px; margin: 0 auto">

<p>View latest data:</p>

<input type="button" value="Live (Joules)" onclick="location='index.html'" />
<input type="button" value="Live (Watts)" onclick="location='watts.html'" />
<input type="button" value="Last Two Hours" onclick="location='TwoHoursData.html'" />
<input type="button" value="Last Day" onclick="location='LastTwentyfourHours.html'" />

<p>Provide Feedback:</p>

<input type="button" value="Access Survey" onclick="location='survey.html'" />

<!--<input type="button" value="Last Week" onclick="location='LastWeek.html'" -->

<p>Download latest data:</p>

<input type="button" value="Last Two Hours" onclick="location='OutputTwoHours.php'" />
<input type="button" value="Last Day" onclick="location='OutputDay.php'" />
<input type="button" value="Last Week" onclick="location='OutputWeek.php'" />

</div>
<script src="http://code.highcharts.com/highcharts.js"></script>

<script src="http://code.highcharts.com/modules/exporting.js"></script>

<p>View logged data:</p>

<input type="button" title="Log" value="Access Logs" onclick="location.href='/DataLog/'" />

<div id="container" style="min-width: 400px; height: 400px; margin: 0 auto"></div>

</body>

<script>
(function(i,s,o,r,a,m){i['GoogleAnalyticsObject']=r;i[r]=i[r]||function()
{i[r].q=i[r].q || []}.push(arguments)},i[r].l=1*new Date();a=s.createElement(o),
m=s.getElementsByTagName(o)[0];a.async=1;a.src=g;m.parentNode.insertBefore(a,m)
)(window,document,'script','https://www.google-analytics.com/analytics.js','ga');

ga('create', 'UA-80592712-1', 'auto');
ga('send', 'pageview');

</script>

</html>
13.2.4. PHP script to collect logged updating data from database (2 hours)

```php
<?php

$con = mysql_connect("localhost","USERNAME","PASSWORD");

if (!$con) {
    die('Could not connect: ' . mysql_error());
}

//data retrieval completed with tutorials from http://www.highcharts.com

mysql_select_db("energy", $con);

$sth = mysql_query("(SELECT * FROM energymade ORDER BY id DESC LIMIT 720)
ORDER BY id");

$data = array();
$time = array();
$data['name'] = 'Solar Data';

while($r = mysql_fetch_array($sth)) {
    $data['data'][] = $r['watts'];
    $time['data'][] = ($r['hour']) + ($r['minute']/100); // + ($r['second']/10000);
}
```
$result = array($time, $data);

//array_push($result,$data);

//array_push($result, $time);

// working code for 2 arrays

// $result = array($data,$time);

//array_push($data);

echo json_encode($result, JSON_NUMERIC_CHECK);

mysql_close($con);

?>
13.3. Google Analytics code

13.3.1. Student behaviour tracking

<script>

(function(i,s,o,g,r,a,m){i['GoogleAnalyticsObject']=r;i[r]=i[r]||function()

{{i[r].q=i[r].q || []).push(arguments)},i[r].l=1*new

Date();a=s.createElement(o),

m=s.getElementsByTagName(o)[0];a.async=1;a.src=g;m.parentNode.insertBefore(a,m))

(window,document,'script','https://www.google-analytics.com/analytics.js','ga');

ga('create', 'UA-80592712-1', 'auto');

ga('send', 'pageview');

</script>
14. References


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Mackness, J., et al. (2010). "The ideals and reality of participating in a MOOC."


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