An increase in the complexity of creative learning in the Advanced Test and Evaluation course will enhance the learning experience of the students.

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This research project will investigate whether an increase in the complexity of creative learning will enhance the learning experience of students completing the Advanced Test and Evaluation course. Although the baseline course meets the learning outcomes, the use of the basic model for the action learning phase of the course is not optimal. The line following robot practical exercise requires minimal factors to be considered through the design of experiments (DOE) process and results in a moderately successful testing outcome. This project endeavours to improve this result by increasing the complexity of the action learning phase, ultimately producing a more assured lesson. The initial stage of the project focused on a critical analysis of the current course and ethics approval, which allowed observation outcomes to be analysed alongside student and lecturer feedback. This formed the themes for further investigation producing options to be implemented into the experimental course. Testing was carried out on these options for viability and assessed against the course learning outcomes. Finally, a new lesson plan for the next Advanced Test and Evaluation course has been developed to provide a more optimal result. The identified improvements use social constructivism theory, which focusses on collaborative, fun and inclusive learning, together with an increase in complexity of the action learning phase, ultimately achieving a greater learning outcome.

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I. Introduction

A. Project Aim
This project aims to investigate whether an increase in the complexity of creative learning in the Advanced Test and Evaluation course will enhance the learning experience of the students. The original course employed a social constructivist style of pedagogy achieved through an active, collaborative and inclusive structure. To improve this instructional approach the course content including assignments, problems and tasks given to the students was reviewed based on the learning outcomes. The course content included the use of the Pololu 3Pi Robot (Figure 1) that was programmed to follow a track. Options were developed and assessed against relevant literature to determine the changes to be trialled in the experimental course. The complexity of the current course was assessed against the pedagogy theories to determine if an increase benefitted the students. Based on the outcomes of the experimental course, a final amendment to the course has been developed to be introduced into the action learning component of the next version of the Advanced Test and Evaluation course.

B. Project Research Questions
The project aims to answer the following research questions:

- Is there an opportunity to add some complexity to the active learning phase of the course to allow a deeper understanding of the course content?
- Is there a limit to the level of complexity that the course can be before it is too complex for the length of course?
- How is the viability of this increase in complexity measured?

II. Research Method

A. Observe Baseline Course
The first step of this research was to observe the baseline course and understand the learning outcomes and how this knowledge is conveyed. Each lesson builds a base for the student in that particular knowledge area. The students then learn further about each area through workshops, which are mini case studies, and then apply this knowledge in the practical phase of each lesson (active learning phase). This format of learning is known as constructivism, as the student’s knowledge is continuously built upon through active learning examples. The lecturer is a mediator for information, creates an environment where students are able to problem solve and produce a meaningful outcome (Altuna & Lareki, 2015).

B. Obtain Ethics Approval
Insight was needed from the lecturer and the students who have completed the baseline course, to identify its current limitations. Students from the mid-year experimental course were also surveyed to assess the efficacy of the course. This student feedback provides insight into their perspectives of the success of the course. The students provided improvement ideas which they recommended to be implemented to better meet the learning outcomes. To survey the students, ethics approval was required.

To gain ethics approval, the project required classification to determine the procedure for approval. The student surveys were classified “Negligible Risk” as there was “no foreseeable risk of harm or discomfort; and any foreseeable risk is not more than inconvenience” (Anon., 2019). This in-turn required a Negligible Risk Research Application form to be completed and approval gained from UNSW Human Ethics Council. Ethics approval was granted and with no specific conditions placed on this particular project, only standard conditions that are given for all projects. The response from the Human Research Ethics Advisory Panel (HREAP) can be found in Appendix A.
C. Survey Lecturer

Following the completion of each course (baseline and experimental), the lecturer was interviewed to gain an understanding of the perceived success, improvement ideas and direction for the course changes to be implemented. This would also provide a method to gain feedback about the success of the course and also whether, in the lecturer’s assessment, the changes made in the experimental course were beneficial and worth keeping for future courses.

D. Survey Students

A six-question survey was sent to each student who participated in the baseline or the experimental course. The survey provided questions to understand the Test and Evaluation education demographics of the students and gain their feedback from the course. A list of the survey questions is provided in Appendix B.

E. Develop Options

Options were developed using the information gained from the lecturer and student surveys to better meet the learning outcomes, and also to improve the students understanding of the learning outcomes. These options increase the complexity of screening before modelling, and also help with some aspects of the course to allow the students to focus solely on the learning objectives part of the course.

F. Assess Options

Of the developed options, and through consultation with the course lecturer, the options were assessed for feasibility, method of introduction and whether they work towards the goal of increasing the understanding of the screening methods.

G. Implement Options

From the assessed options deemed feasible for implementation, a process for adjusting the baseline course to include these options was developed. This includes lessons that need adjusting or moving to better or more appropriate sections in the course. These options were then implemented into the experimental course.

H. Optimisation

Once the experimental course was completed with the implemented options, a subsequent assessment using the method above was carried out. Once completed, options were made available to the lecturer for the 2020 courses.

I. Metric Assessment

Through the validation phase of the course and using post-course group assignments, a comparison assessment was made. This examined whether the students improved their understanding of the fundamental DOE principles in the experimental course, and if the changes made enabled an improved knowledge base for students when assessed against the baseline course.

III. Baseline Course

A. Critical Analysis of Baseline

The baseline course is designed with a diverse pedagogy consistent with the fundamentals of the constructivist theory and focuses on action, collaborative and inclusive learning (Joiner & Brewster, 2017). Each day the students were exposed to selected theory, a workshop (using case studies), and a collaborative and action learning phase. Marquardt & Yeo (2012) reason, complex concepts are best taught through action learning, and it was observed that during the action learning phase the students better understood the information taught in the theory phases. The action learning phase allows the students to attempt different methodologies, which sometimes led to a learning opportunity as their processes did not always result in the achievement of the correct outcome (Mulder, et al., 2016). At the end of the intensive phase, each syndicate submits an assignment designed to show their understanding and outcomes of the process. The lecturer orchestrates an inclusive environment to allow the students to best learn from each other’s experiences whilst completing the tasks (Hyde, et al., 2013). Active learning within inclusive groups allows for learners to solve complex problems more efficiently (Marquardt & Waddill, 2010). The action learning phase is set up to be a fun and enjoyable learning environment, that is not heavily reliant on robot programming skills. It allows students to attempt each task and learn from its outcome.

During the course, the students needed to identify the variables their 3Pi Robot must overcome or consider, to complete the tasks required. Figure 2 shows a cause and effect diagram for the system, which illustrates the potential variables which are the causation of adverse effects on the 3Pi robot for the activity. Through Measurement System Analysis (MSA) techniques, variables were identified as either control/constant variables, noise variables or experimental variables.

The experimental variables were systematically adjusted during the screening, modelling and validation phases to vary the performance of the robot on different line following tracks (Joiner, 2019). If the students do not identify enough variables during the MSA, the screening, modelling and validation processes which reduce the factors further, resulting in an oversimplified outcome that does not allow the student to produce a rigorous model. The reduction in initially identified factors appears to limit the learning outcomes of the students.
As the aim of the course is to expose the student to complex situations and process those situations using the Test and Evaluation methods, the learning situation has to be complex and robust enough to allow that to transpire. The baseline course appeared to have the potential for the students to grasp the course theory, however, the outcome was limited by the number of factors the students could potentially evaluate. Even if the students identified all factors available, the outcome was still a submaximal solution. It also was easy to miss factors which led to a reduced overall outcome.

![Figure 2: Example of a Line Following Robot Cause and Effect Diagram](image)

B. Student Surveys

The students were surveyed once they completed the course. They identified various areas that could enhance the course, of which this report will only deal with the areas that regard the learning outcomes and how the course enables learning. The results of the survey are shown in Figure 3 and Appendix C. The main themes or categories identified include software issues, hardware issues and complexity of the course. These were analysed and taken into account when developing potential areas for improvement for future courses.

Learning of complex material, similar to the topics in the Advanced T&E course, requires the curriculum to be "active, constructive, cumulative self-regulated and goal-orientated" (Tait, 2009). The students identified in the complexity of the course category, that they would like an increase in the complication of the active learning component. They recommended it involve more complexity and thought required and could include mazes or some other challenge that required an increase of variables. Through completing the course, the students appeared to realise the power of the new knowledge they have received, and how an increase in variables, together with robust analysis, eventually provides a more rigorous solution.

Software and basic hardware issues were highlighted, this was a valid problem and would allow more time for the students to concentrate on the learning phase instead of being frustrated by learning how to load and adjust the code. As students were required to focus on administrative frustrations, this reduced the effectiveness of the learning.

The feedback on the complexity of the course required further analysis, as there is a trade-off between complexity increase and timeframe available. How complex the course can be before it becomes too difficult, compared to the ability to be absorbed over the five-day timeframe available. To address this, the options needed to be complex enough to provide the right environment to learn, while being simple enough to understand the background and coding, to spend the majority of time on the complexities.
The information gained by the surveys provides a guide for adjustments that can be made and where the students feel efficiencies can be gained. The course is designed to extend the students to understand the complex course content in a short period. This is achieved through the constructivist pedagogy, the lecturer mentoring the students, and through an inclusive learning environment, where the students work together and share knowledge.

C. Lecturer Survey

The course lecturer provided his insight on the course success, the frustrations encountered, and the direction sought to better meet the learning outcomes. The following were the main discussion points:

A need for more factors to be available in the initial phase of the assignment task was sought, to allow better ability to distinguish between screening and modelling during the activity. Currently, the students have approximately 6-7 potential variables and can easily overlook some factors which fundamentally flows through to a reduced overall result. To ensure students have a sufficient number of variables in the validation stage there needs to be an increased number of initial variables able to be identified by the students, at the early stages of the task.

Too much time learning the robot, due to programming issues, computer incompatibilities and the complexity of the software programs being used. Only problems that need to be solved for learning outcomes should be experienced by students.

Contextualisation, during the first version of the course a Statapult (which used rubber bands to project objects) was used. This was a simple apparatus that had some, yet minimal applicability in the current world. The Statapult was then changed to the Pololu 3Pi robot negotiating a simple tack, as shown in Appendix D, as it was considered to be more technical and better represented real-world problems relevant to the students. The lecturer highlighted a need for ever-increasing credible problems to continue to be relevant and applicable in the real world. Realistic and relevant problems are required to assist with motivation of the learners. Learners need to be able to access their own curiosity and demonstrate spontaneity (Anon., 2011).

In order to maintain relativity with the outside world, the lesson plan needs to be analysed for efficiency gains, and to possibly include areas that are missing completely. The current pedagogy is effective and allows the student to see the whole process, however recently students who have completed the course have requested discussion on a binary approach, which is the probability of the test working or not. This is taught in day five of the course and is therefore not available for students to include in their factors from the beginning.

The information gained from the lecturer’s insight offered further guidance to where adjustments can be made. A focus on increasing the number of variables at validation stage and the need for constant relativity provide strong direction for options to come.

IV. Options

A. Options Analysed

Creating a greater gap between current knowledge and the intended knowledge (less scaffolding), can challenge students to ensure learning is long term. To understand complex theories, students need complex solvable problems to allow information to be truly understood. Authentic and complex problems that can be solved through breaking down the problem into smaller parts, assist the student to learn efficiently and replicate the
process over different examples (Clark & Mahboobin, 2018). This is possible to be achieved through making the areas of the course that are not part of the learning outcomes more streamlined, and those that are part of the learning process more complex. The areas the student focusses their problem-solving skills towards must be directly relevant to the required outcome (Krahenbuhl, 2016). With this in mind, the following potential areas were identified to develop for the experimental course:

1) Maze: An alternate track option would require the robot to learn a maze, and then solve it. The learning component of the maze may be carried out using a left hand to the wall (LHTW) technique, or a right hand to the wall (RHTW) technique. The LHTW technique is pre-programmed to make the robot turn left at every intersection, this systematically checks each available path using a left turn. If the robot finds itself in the same position as once before, it discounts the path and continues to look for a correct path. If the robot comes across a dead end, it carries out a 180° turn and continues its LHTW program. When the robot finds the end of the maze, it outputs an audible beep and shows the minimum turns required on its screen and is ready to carry out the track using this newly discovered output. The robot can then complete the track using the new output. The students estimate how long it will take to complete the mapping of the track. Options for the students to include in the maze are the LHTW program, RHTW program, loops and zigzags. The maze requires every aspect of the line following track, including all variables, however, the maze will have an increase of potential variables as it has increased complexity and options available to the student and lecturer. It is also a progression from the line following track and aligns with the lecturers intent as shown in Appendix E

2) Inclines: The baseline tracks are flat and do not explore the 3D world. The addition of inclines will allow the inclusion of elevation or a third dimension into the track and will provide another aspect that the students will have to factor into their multi-factor designs. The possibilities considered included an up and down ramp of different inclines (5°, 10° and 15° planned), sharp and smooth ramp apexes, different lengths of the ramps and various entry smoothness. The ramps are 3D printed and are able to be added to any line following track or maze as required, as shown in Appendix F

3) Tyres: Currently only thin and wide tyres are used on the tracks. The variable of smooth and rough tyres for the students who might find it viable to have increased grip on certain tracks may be included. The ability to change the tread of the tyres, would have an effect when using the inclines. The tyre tread could be increased when using a smooth incline to ensure grip and increase possible speed on the incline. Another possible variable for the students to explore.

4) Program/Robot introduction Lesson: Some students may have completed a brief introduction to Test and Evaluation; however, this is not a pre-requisite and they are not expected to do any pre-course learning or program introductions. This is beneficial as each student comes into the course with little to no prior DOE knowledge and will need to learn and adopt the DOE theory to complete the course. This also means that there is a steep learning curve initially, especially when it requires the use of the robot. This is evident as some students appeared to struggle to learn the course content and apply it to the robot through the required programs. The robot has pre-made code requiring minimal adjustment to suit specific choices made by the students, however, it relies on the student being able to learn and modify the code in the short period. The course also relies on the students being familiar with or able to learn Atmel Studio 7, a program that is used to manipulate the robot code. They also need to understand how to get the robot, Atmel Studio 7 and the Pololu code to all work in sync. A pre-course introduction to Atmel Studio 7 was assessed as a possible option, as it would ensure that the students can download the program, it works on their personal device before starting the course and provides slight familiarity before the course beginning. Also, a code adjustment example would save the student time in learning how this is carried out.

5) Lesson Plan Adjustments: In order to integrate some potential adjustments, the lesson plan would require modification as some learning activities may need to be introduced earlier than their current planned time. This may provide an opportunity to shift the course to align with current ADF/real-world requirements. The lecturer spoke of how past students have requested discussion on a binary approach, this could be brought into the course and moved from day five to an earlier session.

6) Contemporise for the future: The lecturer identified that he was constantly striving for ways to keep up to date with technology and to ensure that the course is modern at all times. This is evident in the course evolution from the Statapult to the line following robot. The course needs to continually advance and continuously challenge the students to enable them the ability to use this knowledge in real-world applications. Constructivists promote that learning needs to take place in an authentic environment (Brown & Duguid, 1991). The next step may be to bring in an autonomous feature or a different type of outcome. If the robot was to continue as the medium, then instead of timing the event and striving for the more efficient way from start to finish, an actual outcome may be an option. For example, the robot may have to navigate its way to the end of the track, which happens to be inside of a box. Once inside, the robot would have to read a sign or be able to view the sign, by photo or video, to be read by the students. This would represent another variation to the line following track or maze and have a real-world application as
most problems require an end goal, that isn't simply a time. The autonomous feature may be unavailable currently, however as technology evolves, this may be a useful way to introduce it to students and be extremely beneficial to their workplaces.

B. Changes Developed and Implemented

The following areas were identified and developed for inclusion into the experimental course. These align with the course outcomes and provide a more complex environment for the students to practice their newfound Test and Evaluation knowledge. These were able to be included in the current course schedule and were sufficiently realistic to be implemented in the experimental course.

1) Maze: When faced with more challenging learning experiences, students may achieve greater learning outcomes (Frensch & Funke, 2014). For this reason, the line following track was removed and replaced with a maze track in the experimental course. This was deliberately done as it was more challenging and required more understanding to create a rigorous model. The maze track required the robot to learn and solve a student-built maze. The maze was extensively researched, and multiple mazes were designed, adjusted and tested before inclusion into the experimental course. The maze requires every aspect of the line following track, including all variables, however, the maze had an increase of potential variables as it has increased complexity and options available to the student and lecturer as shown in Appendix E. Adding the maze to the course also required the course to be adjusted, as the maze track is different from the line following track. It was decided that the students have to program their robot to only learn the course, instead of learning and then solving the maze in the fastest time. It also meant that demonstration mazes and familiarity with the code was essential as general assistance and troubleshooting during the course was required.

2) Inclines: Options for students included an up and down ramp of different inclines (5° sharp apex and smooth apex and 10° sharp apex). The ramps were 3D printed and able to be added to any line following track or maze as required by the course. The ramps were printed white with a black line added post-print, allowing seamless inclusion into the robot’s path as shown in Appendix D. The code was tested so that the ramps could work with the robot, and after multiple attempts, it was proved a viable inclusion.

3) Tyres: Thin or thick tyres were made available; this was pertinent when assessing the ability for the robot to navigate over the incline as the height between the robot sensor and the line to follow provided some challenges. The thick tyres lowered the profile of the robot and hence reduced the sensor assessing distance. This also provided options for students as the thin tyres did not have as much grip as the thick tyres, which is relevant when encountering inclines and gives further options to be assessed throughout the experiment process.

4) Program/Robot Introduction Lesson: The students were provided with two pre-course guides to allow familiarisation of the Atmel Studio 7 software and how to install the code onto the robot. The students are not expected to be an expert in writing or manipulating code, however, this gave them a step-by-step guide as to how the process should be carried out and allowed them to practise before the course. This also ensured that each student could download the software and if issues had arisen, course staff are aware at the start of the course and able to rectify the issue.

5) Lesson Plan Adjustments: The lesson plan was adjusted slightly to integrate the binary approach, which was then able to be used in the maze solving robot active learning activities. This provided the students with the ability to include binary options in their model earlier than previous courses. As shown in Appendix G

6) Contemporise for the future: The addition of the maze was decided as a way to progress from the line following robot to a maze solving robot. This is similar to different learning examples that other universities use and allows a more realistic example of DOE compared to previous renditions of the course (Balaji, et al., 2015).

V. Experimental Course

A. Observation

The experimental course had fewer participants than the baseline course, comprising of 11 members of varying ages, experience and job description. It was evenly spread between defence members and defence contractors. The course members appeared to be more familiar with the software and also had questions straight away which was different from the baseline course. This was due to the how-to guides being available before course, and hard copy examples being available during the course. The lesson plan adjustment with the addition of the binary approach worked well as some members had experienced this before and could relate and give examples to the rest of the class.

The change from the line following robot to the maze was done on the second day. The first day required the students to simply run the code and to ensure the robot worked as programmed. This was done on the line following track and when it came time to use the robot as per the DOE process, it was switched to the maze solving mode. This proved to work well as it gave the students some experience with a simple robot track and
programming the robot before moving to a more complex version later in the course. The students need to be able to link previous knowledge and build on it quickly. Constructivism builds on prior knowledge as the student must make connections between new and old information within their zone of proximal development (ZPD), the gap between current knowledge and new knowledge to be learnt (Kostakopoulou, 2018). Regardless of scaffolding, if the ZPD is too large, then students will fail to link the information to their previous knowledge (Nouri, 2012).

The addition of inclines provided some frustration to the students as they proved hard to navigate, however, this forced the students to learn the code more thoroughly and eventually were able to utilise the inclines in their testing process. The validation phase of the course appeared to be successful. Some minor hardware issues arose, however, the students appeared to understand the process well and were able to apply their learning to the validation mazes with confidence, producing suitable outcomes.

**B. Student survey**

The results from the student survey are found in Figure 4 and Appendix H. The following outcomes are of note:

1) Pre-course Reading: The students indicated that they would like the code to be made available earlier than on day-one of the course, in an attempt to familiarise themselves with it. They also wanted a general idea of where to adjust, and what range of adjustments the code required.

2) Software: The was a reduction in the software issue encountered on the course due to the pre-course how-to guides, and only some minor issues arose during the course that were mentioned.

3) Course Planning: The Course planning feedback was not related to learning outcomes and will not be discussed.

4) Code assistance: The survey indicated that the students were happy with the changes to the maze and also the addition of the inclines. Their main area for improvement was the range of some of the variables in the code. The course specifically does not provide ranges for certain variables as the lecturer wants the students to find the ranges themselves. This is to simulate a real-world problem where the ranges for parameters are not provided and would have to be found through testing or via a subject matter expert. Basic ranges for the variables were provided to the students and will be in the future.

Figure 4 illustrates that there are still software issues before and during the course. These issues cannot be fixed totally as students need to be able to use their own personal devices during the assignment, once the intensive part of the course is complete. Therefore, we cannot provide computers with the software installed. The students have to check that the software works before starting course using the guides or highlight this with the lecturers at the start of the course for assistance.

![Figure 4: Experimental Course Feedback ideas](image)

The students have asked for a more defined problem and more detailed lecture slides. This was discussed and decided that as the course tries to imitate and prepare for the real-world, it would not be changed. This is because a real-world problem would be a perfectly defined problem or a with a set of perfect instructions. The students have to work the answers out for themselves and therefore it will not be changed. A variable functional range and pre-course access to the code are both good ideas and will be made available for future courses. The variable range will be carefully assessed as the lecturer mentioned that he did not want the code changes to be made too easy for the students, and exploration of the code range was an important aspect of the DOE process and the task
itself. This supports the pre-course reading and code assistance grouped ideas. The remaining grouped ideas were not addressed as they were deemed course administration and do not impact the course learning outcomes specifically.

C. Lecturer Survey

The lecturer was extremely satisfied with the changes that had been made to the course. The students had to think about the outcomes at each stage and it was not as straightforward as the previous version. The students were required to think wide in terms of variables, to work out the few that mattered for the final outcome. The lecturer was especially pleased that the students were able to create a predictable performance model and when asked to assess and predict the outcome of their model, the results were close to their predictions.

The lecturer also mentioned it was valuable that some students got a solid performance from their robot however were unable to complete the tasks at some stages due to not completely understanding the robot and its variables. This was a good lesson in itself for the students as they realised their mistakes and understood that they needed a more thorough model to produce a successful prediction.

One of the main concerns with the baseline course was the lack of reinforcement of lesson 2 and 4, which are the screening and validation process. The lecturer was incredibly happy that the experimental course addressed these issues through improved screening reinforcement, and improved validation of model and equipment for predictable performance. This was a major concern that this project was trying to address, and the feedback shows that it has been successful.

VI. Continual Improvement

The experimental course was a success and met the learning outcomes, however, to continually improve, together with observations and the student feedback from the experimental course, the following options will be prepared for the 2020 courses.

1) A broad and definitive variable range will be provided to give the students a general guide when altering the variables during each phase. This will be a large range and will by no means reduce the testing that has to occur, and it ensures that the students use their time as wisely as possible and have a small amount of assistance in this area. This is representative of a subject matter expert in the real-world application and is consistent with the course intent.

2) The Code will be given to the students before the course so that they can familiarise themselves with the code in preparation for the course beginning.

3) The software and code how-to guides will again be made available to the students with more emphasis on understanding and using these guides before the course begins.

VII. Comparative results and Discussion

To assess the changes made and the success of the experimental course, a metric was needed that compares the level of learning from the baseline course, to the level on learning in the experimental course. This is difficult as it is hard to quantify if a student has an enhanced learning of the course, simply from the way they complete the course. A true indication of the changes made, which flow onto the ability for the students to learn and absorb the information presented in the course, would be to have two students perform an individual research test design and analysis on the same area, once they have completed either the baseline or experimental course. This would also have margins for error as no two people think alike or apply knowledge the exact same way. Therefore, this method may not produce clear results either.

It was decided that although both courses had different mediums (line following robot compared to maze solving robot), a comparison could be used as the basic theory the course teaches had not changed, only the active learning phases. Therefore, it would be appropriate to measure the student’s level of understanding though the validation phase, which has built on the other phases. The assignment results can also be assessed to compare if the level of understanding has increased.

A. Validation phase

The capstone of the intensive phase of the course is validation, which culminates on the fourth afternoon. Students nominate their top five parameters that impact their system and pass them to the lecturer. From here, the lecturer then picks three parameters and inputs into the software to produce final tracks for the students to create. This is done using a Nearly Orthogonal Latin Hypercube Design (NOLHD), which is a statistical method for generating a near-random sample of parameters from a multidimensional distribution. After the tracks are designed and built from these parameters, each team is asked to assess each track and estimate the time it would take for their robot to complete the track. Students must assess the complexity of the tracks to then adjust their settings based on their previous testing. Each syndicate then attempts each track three times and records their times and deviation from their estimates. This provides a competition like atmosphere and allows the previous testing and hard work to be put to use against other teams. This also provides an opportunity for the students to work out if their testing was broad and rigorous enough to cater for the NOLHD model.
Students from the baseline course carried out this process suitably, however, it was evident that the lack of initial factors hampered their true understanding of the course as a whole. Whilst some students understood the process adequately and produced a sound model for estimating the time to complete the track, other teams did not quite grasp the course completely which took away from the total success of the course. They also did not spend enough time at each stage of testing and realised this later on in the course when their model was not as good as it could have been.

**Figure 5: Experimental course students displaying their tracks before validation testing.**

In the experimental course, each team appeared to understand the DOE concepts and were able to successfully predict the performance of the robot on the validation tracks. Some teams were able to complete the track three times within two seconds of their estimation, which was a great result. Other tracks were found to be difficult for their robot which resulted in a not complete. Whilst students learnt more from making mistakes and solving each problem, positive feedback is necessary to maintain a student’s motivation (Mulder, et al., 2016). This gap in knowledge was realised quickly and adjusted to produce successful track completions. Through undertaking an action to solve a problem, the students can make mistakes and then reflect on those mistakes. This reflection is where the action is turned into knowledge (Dilworth, 2010). This feedback was during the validation, and even when moving from track to track there was a level of reflection happening, which was immediately turned into knowledge.

**B. Knowledge through assignment**

The baseline syndicate assignments were assessed for level of course content understanding against the experimental course. Even though the baseline course used line following robots and the experimental course used maze-solving robots, their base level of DOE understanding was assessed. This was to decide if the changes to the course had enhanced the learning of the students and enabled them to absorb and understand more of the course content with the adjusted and more complex active learning phases.

The baseline course had a good grasp of the course content and expressed a good level of understanding in the assignment. Some syndicates did accept that they did not fully appreciate the underlying requirements and specifics of data collection during the MSA exercise, which lead to a less rigorous eventual model. This shows that they understood that they did not do that part of the course well and identified that it cost them in the later stages. Whilst acceptance of the fault was admirable, the underlying issue that it happened in the first place, indicates that this particular syndicate did not understand the relevance of the MSA, and the flow-on effect if not done well. It was also evident that most syndicates used similar tracks when gathering data during the test runs, which in-turn produced similar output results. This is not what is desired, as in the real world, no two problems are the same and a range of testing is required to complete the process and find the optimum model. Variations in test track types were required to give varying data to take into the next step in the process.

The experimental course also grasped the content well, however they found it hard at times to adjust the code to test what they wanted to test. Once overcome, they tried all variations of the tracks and appeared to do all facets of the DOE process well. This was evident in their assignments as all teams identified and understood all processes and realised the importance of carrying out each stage to a high level. Each team identified the exact part of the process they did not do correctly and the corresponding outcome due to that mistake. The assignments were to a
high standard and it was evident that the more complex task that the students had to overcome, promoted their Test and Evaluation learning.

The adjustment from the baseline to the experimental course was a moderate enhancement of complexity and showed improved results from the students. It was evident that a further increase in the complexity would result in a too significant leap for the students. Any additional increases in complexity would cause the students ZPD gap to be too large for the current course length.

C. Application versus understanding

A different method for assessment of the learning, is the number of questions that were asked by students. The experimental course asked an enormous amount of questions during the action learning phase, mostly about what they want to test and reproduce and “how do I do it”. Which indicated that they understand the content extremely well and had difficulty applying it into the robot. This is the required outcome, as the fundamentals of the Test and Evaluation process using DOE should not change from application to application, however, the way it is applied is the difficult part that usually requires a subject matter expert (SME) or a high degree of system knowledge to carry it out.

VIII. Conclusion

This research has shown that through increasing the complexity of the Test and Evaluation course, the students can achieve improved outcomes with the use of a more complex medium. This has been carried out through an addition of mazes, inclines and “how to guides” to the active learning phase of the course. Through this increase of complexity, a deeper level of learning was achieved by students of the experimental course, when compared to the baseline course. Students were exposed to a larger number of potential factors which, when passed through the DOE process, created a model with increased rigor and predictability. This was the primary aim of this research and has proven to be effective.

The feasibility of the complexity increase was measured through assignments and the validation phases of the course, which indicated that the changes made were beneficial and worthwhile. With the changes implemented, the level of complexity has approached its maximum level, with a further increase requiring the course to be lengthened or a heavy pre-course workload to be added. Both of which are not desirable. The course has reached its complexity limit and only small continual improvement changes will be beneficial as technology improves. The experimental course now provides the students with a good foundation of knowledge of Test and Evaluation using the DOE model and provides a good baseline for future testing in their chosen fields.

VIII. Acknowledgments

I would like to acknowledge GPCAPT Keith Joiner for his passionate assistance throughout this research, it has been a pleasure to work with him on the courses and I have learnt a lot from his constant guidance. Thank you very much Keith.

I would also like to acknowledge my wife, Rachael, for her continual support throughout this research.
Bibliography


Appendices

Appendix A. Letter of confirmation of Ethics Approval

The following shows the response from the HREAP Executive following Ethics Approval application. It outlines the specific condition to this project and the general condition for all projects.

Figure A1: HREAP Response
Appendix B. Post Course Questionnaire

The following shows the Post Course Questionnaire that was given to the students following the baseline and experimental courses.

Figure A2: Post Course Questionnaire
Appendix C. Post Course 1/2019 Feedback grouped into themes

The following shows that software was the most common theme that was mentioned in the survey. This includes pre course software awareness, through course expertise and also how-to guides for the students. Other notable themes were the hardware and its management and also the complexity of the course was well represented.

![Baseline Grouped Ideas](image)

**Figure A3: Baseline course feedback responses grouped by theme**

Appendix D. Example Line Following Track

An example of a line following track which requires the student to take into account all variables to determine the potential time to complete the track.

![Line Following Track 1](image)

**Figure A4: Line Following Track 1**
Appendix E. Example of a Maze

The following show an example of a maze that the robot has to learn and then complete in the least possible turns. Mazes can be made with 90-degree turns or can include inclines, loops or zig zag turns.

Figure A5: Example of a Maze

Appendix F. Example of and Incline

The following in an example of a 5-degree incline that was trailed as an addition to a track. The Robot is shown to be approaching the apex of the ramp having negotiated the change from the level track surface to the incline of the ramp.

Figure A6: 3Pi Robot on an 5-degree incline
Appendix G. Amended course timetable

The following course timetable was utilised in the experimental course. It features a new position for the Binary Live/die cases and also a robot introduction prior to the 3pi Robot MSA component.

<table>
<thead>
<tr>
<th>Time</th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
</tr>
</thead>
<tbody>
<tr>
<td>0800</td>
<td>Course Introduction</td>
<td>L3: DOE Terminology &amp; designs</td>
<td>L5: Modelling</td>
<td>L6: Historical Data &amp; residual analysis</td>
<td>L9: HTT Cybersecurity testing</td>
</tr>
<tr>
<td>0900</td>
<td>L1: DOE</td>
<td></td>
<td>L5: Modelling</td>
<td>W6: Body Armour</td>
<td></td>
</tr>
<tr>
<td>0945</td>
<td>Morning Tea (Short)</td>
<td></td>
<td></td>
<td>W7: Target effects</td>
<td></td>
</tr>
<tr>
<td>1015</td>
<td>Test statistics review and Exercises</td>
<td>L4: Screening Designs</td>
<td>L5: Modelling</td>
<td>W8: DOE in Big Data: Ship Supportability</td>
<td></td>
</tr>
<tr>
<td>1110</td>
<td>L2: Pre-test work</td>
<td>W2: 3D printer (L12)</td>
<td>W4: 3D printer model</td>
<td>L7: High Throughput Testing</td>
<td>W10: Cybersecurity screening example</td>
</tr>
<tr>
<td>1200</td>
<td>Lunch</td>
<td>W3: Home brew (L18)</td>
<td></td>
<td>L10: Cultural issues - Ex Asut‘use</td>
<td></td>
</tr>
<tr>
<td>1350</td>
<td>W1: 3D Printer MSA</td>
<td>A1: 3pi robot model</td>
<td>L8: Representative sampling</td>
<td>W11: Validating test cricket log model</td>
<td></td>
</tr>
<tr>
<td>1430</td>
<td>A1: PF/CE/CNX/SOP</td>
<td>Afternoon Tea</td>
<td>Afternoon Tea</td>
<td>Afternoon Tea</td>
<td></td>
</tr>
<tr>
<td>1500</td>
<td>Short Afternoon tea</td>
<td>A1: 3pi robot Screening</td>
<td>A1: 3pi robot model</td>
<td>A1: 3pi robot validate</td>
<td></td>
</tr>
<tr>
<td>1700</td>
<td>A1: 3pi robot MSA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure A7: Amended course timetable*
Appendix H. Post Experimental Course Feedback grouped into themes

The following shows that course planning was the most common theme that was mentioned in the survey. This includes more detailed lecture notes and a more defined problem. This was outside of the scope of this research paper. Other notable themes were the lack of complexity of course, and the reduction in the software issues that were encountered in the baseline course.

![Experimental Grouped Ideas](image)

*Figure A8: Experimental course feedback responses grouped by theme*