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Introducing Remote Design Studios: A Conceptual Reflection

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ABSTRACT

CONTEXT

The engineering profession is changing rapidly, as are the needs of our undergraduates, which demands new approaches to learning and teaching. To become an engineer, students must combine sound theoretical knowledge with practical skills and experience. However, the growing trend in online education is creating many challenges for developing equivalent practical skills, knowledge, and expertise.

PURPOSE

This paper addresses the following research questions:

- What are the objectives of modern engineering laboratories?

- Can the Remote Design Studios concept effectively achieve such objectives?

METHODOLOGY

To establish objectives for modern engineering laboratories, we adapted the instructional objectives proposed by Feisal and Rosa (2005), adding criteria for sustainability, equitable learning, new technology and learner engagement, and ensuring complete coverage of the application and professional graduate attributes domains in the EA stage 1 competencies. We then developed the concept of Remote Design Studios by introducing a physical remote and digital twin approach in the laboratory experiments where students simulate a given problem using HEC-RAS software and verify the result with laboratory experiments remotely. We then applied the autoethnography technique to evaluate the effectiveness of traditional and new approaches by engaging two academics working in different capacities and the Laboratory Supervisor.

STUDY OUTCOMES

The Remote Design Studio engaged students in a longer and deeper learning process incorporating opportunities to develop skills, knowledge and confidence through exploration and trial-and-error use of industry-standard software. While not all laboratory objectives were enhanced through the self-assessment, this concept improved overall outcomes for the laboratory, as reflected in staff and student feedback.

CONCLUSIONS AND RECOMMENDATIONS

The trial of Remote Design Studios was successful. The concept created workload efficiencies for academics and Laboratory Supervisors and provided a more equitable practical learning experience for online and on-campus students. However, the idea is recommended to include activities across several weeks to obtain the most value from exposure to industry-standard software and time remotely connected to the engineering laboratories. Finally, to avoid excessive workload, it is not recommended to replace straightforward laboratory activities with this concept.

KEYWORDS

Digital twin, Remote laboratory, instructional laboratory, work-ready graduates

Introduction

The main goal of engineering education is to prepare students to practice engineering as their career (Feisel and Rosa 2005). To improve the work readiness of graduates, education providers should evolve and continue to change, matching the profession's demands (Litizinger et al., 2011). Instructional laboratories have been an integral part of engineering education from the earliest days to provide learning by doing experiences. However, it is time to evaluate laboratory outcomes for both on-campus and online students.

There have been a few fundamental changes that warrant a review of the role of the instructional laboratory in engineering education. The key points are a) increasing use of software by the engineering profession, b) use of advanced equipment to gather detailed information and c) cost and benefit of the laboratories to all students and universities.

All the professions now routinely use digital technology, so technology training has been part of their education (Holmes, 2010). The use of technology, namely software, has been an integral part of any engineering analysis and design. One example includes job advertisements for Water Resources Engineers seeking competence in TUFLOW, HEC-RAS, MUSIC, 12D, GIS, WBNM, RORB, XPSWMM etc. To become an engineer, students need sound theoretical knowledge, combined with software and modelling experience, which are becoming more essential.

Williams (2012) explains that there is a relentless increase in precision demanded from medical equipment and pharmaceutical product manufacturing, but the expectation of accuracy is increased in all sectors. The details of parameters required in engineering design and analysis have also significantly increased. Engineering equipment is increasingly becoming complex to measure small details with high accuracy. However, these types of equipment can be too complicated to learn in a short period. So, laboratories for undergraduate students are becoming a place to develop a feel for engineering rather than concrete learning of all aspects.

Remote laboratories are a relatively new and proven concept. Brinson (2015) found that students' learning achievements are equal to or higher in remote or hybrid laboratories compared to traditional methods. Li et al. (2020) also concluded that the remote laboratories successfully cultivated teaching and learning conditions like the physical environment. Viegas et al. (2018) found no difference in grades with remote laboratories, but students' satisfaction depended on perceptions of the laboratory. Lal (2020) observed that maintaining a similar environment, for example, using the same instruction sheet, also promoted and preserved the learning outcomes. From their research, Hernández et al. (2019) also concluded that remote laboratories are a serious alternative to complement or even replace the traditional approach for many reasons, including lower initial, operation and maintenance costs, plus the ability to encourage active learning.

The value of traditional instructional laboratories is another aspect to consider. There is significant time and cost to attend university to complete laboratory exercises, especially for online students. The cost required to maintain the laboratories by the university is also substantial, especially for institutions with multiple campuses, all providing equitable learning environments. Many alternatives, such as remote and virtual laboratories, were trialled to achieve the learning objectives, and most were successful. However, with the rapid expansion of digital technologies, new learning avenues exist, such as videos and simulations, which can replace the need to attend the laboratory to some extent.

This research presents the concept of replacing the traditional instructional laboratory with a Remote Design Studio trialled for one activity in a Hydraulics and Hydrology unit to assess effectiveness. Students prepare a digital twin of a physical problem. They use industry-standard software to solve and verify their results with the physical experiments via Zoom without travelling to the university. The proposed laboratory differs from the traditional instructional approach, so the skills, knowledge and experience also differ. However, it is hypothesised that the students will learn most of the skills expected from the traditional approach and develop additional skills, including modelling and simulation experience. For comparison purposes, the 13 fundamental laboratory objectives set by Feisel and Rosa (2005) were expanded in this project to introduce the use of new technology, promote sustainable development, and ensure activities were accessible and enjoyable for all students. We also aligned the objectives with the Engineers Australia Stage 1 Competencies covering the pillars of application and professional graduate attributes (Table 1).

Table 1 Updated objectives of Engineering laboratories linked to Engineers Australia Stage 1 Competencies [Adapted from Feisel and Rosa (2005) in a modified form]

Objectives	Cognitive domain	EA
1: Instrumentation	Apply appropriate sensors, instrumentation, and/or software tools to make measurements of physical quantities.	2.2
2: Models	Identify the strengths and limitations of theoretical models as predictors of real-world behaviours. This may include evaluating whether a theory adequately describes a physical event and establishing or validating a relationship between measured data and underlying physical principles.	2.2
3: Experiment	Devise an experimental approach, specify appropriate equipment and procedures, implement these procedures, and interpret the resulting data to characterise an engineering material, component, or system.	2.2
4: Data Analysis	Demonstrate the ability to collect, analyse, and interpret data and to form and support conclusions. Make order-of-magnitude judgments and use measurement unit systems and conversions.	2.1
5: Design	Design, build, or assemble a part, product, or system, including using specific methodologies, equipment, or materials; meeting client requirements; developing system specifications from requirements; and testing and debugging a prototype, system, or process using appropriate tools.	2.4
6: New Technology^	Apply technology, data, industry software, specialist bodies of knowledge and principles of systems engineering to develop complex systems incorporating modelling and simulation skills.	2.2
7: Sustainable development^	Demonstrate sociotechnical awareness by effectively exploring opportunities to advance the sustainability of engineering activities.	2.3
	Psychomotor domain	
8: Psychomotor	Demonstrate competence in the selection, modification, and operation of appropriate engineering tools and resources.	2.2
9: Sensory Awareness	Use the human senses to gather information and to make sound engineering judgments in formulating conclusions about real-world problems	3.5
10: Accessibility^	Employ appropriate technologies and other strategies to enable immersive practical learning for students studying remotely or with limited access.	-
	Affective domain	
11: Learn from Failure.	Identify unsuccessful outcomes due to faulty equipment, parts, code, construction, process, or design, and then re-engineer effective solutions.	3.4
12: Creativity	Demonstrate appropriate levels of independent thought, creativity, and capability in real-world problem-solving.	3.3
13: Safety	Identify health, safety, and environmental issues related to technological processes and activities, and deal with them responsibly.	3.1
14: Communication	Communicate effectively about laboratory work with a specific audience, both orally and in writing, at levels ranging from executive summaries to comprehensive technical reports.	3.2
15: Teamwork	Work effectively in teams, including structure individual and joint accountability; assign roles, responsibilities, and tasks; monitor progress; meet deadlines, and integrate individual contributions into a final deliverable.	3.6
16: Ethics in the Laboratory	Behave with the highest ethical standards, including reporting information objectively and interacting with integrity.	3.1
17: Engagement and learning^	Complete activities which effectively engage deep learning techniques and learning enjoyment.	-

^ Objectives added by this study to promote new technology, sustainability, equitable student experience and student engagement

Traditional Instructional Laboratory

One of the components of the laboratory is to conduct open-channel experiments. Students run the experiments following predefined procedures and equipment outlined in the instruction sheet. A 5 m long open channel is set on three different slopes to create three separate scenarios. The sluice gate is fixed near the downstream end of the channel, and water is admitted by opening the control valve. One of the depth gauges is placed 1 m from the inlet to the channel, and the other just upstream of the sluice gate. Adjustments are then made to produce conditions of uniform flow along the length. When the two gauges show identical readings, measurements should be taken of the depth at 1 m intervals along the channel to establish the mean depth of the channel flow and discharge over a timed interval. In this manner, mean depth and discharge measurements should be obtained for about five different depths ranging from 20 mm to 80 mm. These readings are repeated with the channel set at two other slopes. Students are expected to analyse the results to calculate Manning's roughness coefficient, compare them with textbook values and prepare laboratory reports in a team.

Remote Design Studio

Students are divided into teams and given topographical and water flow information of a lab-scale channel. The goal is to design a culvert within an influx limit for the given topographical and road information. To accomplish this task, students use the HEC-RAS software. The first task is to create a digital twin in HEC-RAS and calibrate and validate Manning's roughness of their digital channel for the given flow and water level scenario. Once verified, the next step is to design the culvert. Students can select predefined circular culverts of different diameters and numbers of barrels.

After completing the design, students validate their simulated culvert model with the physical experiment in the laboratory. Student teams are connected via Zoom to the laboratory at their scheduled time. The students then advise the Laboratory Supervisor on the channel settings for slope and flow rate, the culvert to use, and the data to collect. Students must answer questions on the theory of open channel flow, explain any assumptions made in simulations, list expectations of their results during the experiments, and reflect on the results. After the experiments, the students expand their model to conduct a sensitivity analysis to evaluate the effect of different culvert parameters on the water surface profile and upstream influx.

Methodology

This article uses autoethnography, a qualitative strategy, to combine the perspectives of the Laboratory Supervisor with academics working at different course levels. Analytic autoethnography allows understanding a broader phenomenon by reflecting on personal experiences and data (Anderson, 2006). The technique assumes that researchers' perceptions create valid data about a particular issue, in this case, the two types of laboratory experiences. So, the three authors collectively drew on personal experiences to evaluate the laboratories against the 17 objectives using the Likert scale (1-5), with one being low and five being high. Before assigning a score, they discussed how the objectives were achieved in a meeting. Finally, all authors shared a brief reflection on their perspectives. The three views are then summarised to provide new insights. All authors have been involved with the unit for several years but at different levels, one as the Unit Coordinator, the second as a Head of Course, and the third as a Laboratory Supervisor. There is potential for the authors to be influenced by each other's experiences. However, this is not considered a shortcoming of the methodology because the perspectives came from three different and relevant angles leading to a comprehensive evaluation. A comparison of activities completed by students in the traditional instructional laboratory and the Remote Design Studio is shown in Table 2.

Table 2 Activities conducted by the students in the two laboratory versions

Traditional Laboratory	Remote Design Studio
-	Construct the HEC-RAS model for open channel flow.
-	Calibrate Manning's roughness of the channel using supplied flow data.
-	Design an optimum culvert to achieve the design flow and channel conditions.
Attend the laboratory induction. Complete the risk assessment.	-
Read the Laboratory instruction sheet.	Read the laboratory instruction sheet.
Change the slope of the open channel and adjust the flow with help from staff.	Advise the laboratory staff on the flow and slope of the channel and watch the process of setting up the equipment.
Measure the water surface profile and flow and take notes	Watch the laboratory staff take measurements of the water surface profile and flow without the installed culvert and take notes.
-	Provide instructions to the laboratory staff on where to install the designed culvert. Watch the laboratory staff take measurements of the water surface profile and flow and take notes.
Analyse the data.	Analyse the data.
-	Compare the simulated and observed flow with culverts to comprehend the accuracy and limitations of simulation software.
-	Conduct sensitivity analysis on the water surface profile by changing culvert parameters.
Produce a laboratory report.	Produce a design report.
Work in a team.	Work in a team.

Evaluations and Reflections

Table 2 demonstrates that the Remote Design Studio engages students in a longer and deeper learning process incorporating opportunities to develop skills, knowledge and confidence through exploration and trial-and-error use of industry-standard software. To be effective, Remote Design Studios must be embedded within units, usually spanning weeks of activities, to adequately guide students through the entire process. Hence, employing this approach to replace straightforward laboratory activities is not recommended as this could create excessive workloads. However, the new approach provides an attractive option in disciplines where practical and technical competence is essential, and modelling and simulation are applied to inform system designs.

Table 3 shows the collective evaluation by three authors to what extent and how the objectives of the laboratories were met. The result indicates that the Remote Design Studio achieves the objectives better in some areas such as design, simulation, accessibility, learning from mistakes and creativity. There are other areas where there is no overall difference, such as instrumentation/software, control of the experimental approach, data analysis, and engagement and learning. Some other objectives were achieved better by the traditional method, such as psychomotor, safety, teamwork and ethics. The average score of the conventional approach in terms of overall objectives is 2.6/5.0, and the Remote Design Studio is 3.1. With the lesson learnt from this year's trial, there is a greater potential for improvement to achieve higher overall results, as shown.

Table 3 Evaluation of the objectives achieved by the Traditional lab (TL), Remote Design Studio (RDS) and future improvements (FI) (1-5 Scale).

Objectives	TL	RDS	FI	Comments (How the students were involved and the future)
1: Instrumentation	3	3	4	**TL**: No specific software tools or sensors were used. Students used basic instruments with some assistance from the lab staff. **RDS**: Extensive use of HEC-RAS software but no direct involvement in measurements. Students watched and recorded the measurements via Zoom. **FI**: None
2: Models	4	5	5	**TL**: Used measured data to derive theoretical Manning's roughness and compare it with the textbook. **RDS**: In addition to the previous work, students create and calibrate the numerical model and compare the results of simulated and observed data. **FI**: Exposed to a more complex real-world scenario.
3: Experiment	3	3	4	**TL**: Students had more control over the measurements but less choice in the experimental procedure. **RDS**: Students have higher flexibility on the experimental procedure and material selection but no direct control over the measurements. **FI**: None
4: Data Analysis	4	4	5	**TL**: Students analyse the experimental data. **RDS**: In addition to analysis of the experimental data, students do sensitivity analysis. **FI**: None
5: Design	1	4	5	**TL**: Students follow the specified experimental procedure with no design elements. **RDS**: Students develop a numerical model to design a culvert. **FI**: There is a potential to add more design elements.
6: New Technology^	1	5	5	**TL**: No simulation exposure. **RDS**: Students conduct a proper simulation of a given scenario, including calibration and validation of their results. **FI**: None
7: Sustainable development	1	1	3	**TL**: None. **RDS**: None. **FI**: Sustainability can be included in terms of sizing the structures to optimise resource use.
8: Psychomotor	3	1	1	**TL**: Students involved in the limited operation of engineering tools. **RDS**: No direct contact with the physical devices. **FI**: None
9: Sensory Awareness	1	1	3	**TL**: Limited. **RDS**: Limited. **FI**: Awareness can be improved via scenario analysis of the numerical model, such as erosion, hydraulic jump formation etc. and their potential impacts.
10: Accessibility	1	5	5	**TL**: Accessibility has been an issue for distance students. The problem was severe due to COVID. The travel cost for distance students has always been a concern. **RDS**: No limitation on attending the lab. **FI**: None.
11: Learn from Failure	3	4	5	**TL**: No opportunity to re-do the experiments but could learn from the mistakes if identified correctly. **RDS**: There is a chance to modify the model and re-engineer the solution. Many analyses can be done, and easy to learn from failure. **FI**: There is a potential to alter the project and increase the opportunity to learn from failure.
12: Creativity	1	3	5	**TL**: Limited imagination. **RDS**: Some imagination opportunity to propose the solution. **FI**: More creativity opportunities can be introduced for future projects.
13: Safety	4	2	3	**TL**: Students conduct Risk assessments before the lab. Lab induction was compulsory before the lab. There were some risks of accidents in the lab. **RDS**: Students do not directly participate in the risk assessment and safety because there is no immediate risk to the students. **FI**: The risk and safety aspects of the design can be introduced. The safety procedures of the experiments can also be explained before the experiment.
14: Communication	3	4	4	**TL**: Lab report only less opportunity for complex communication. **RDS**: Students explain the open-ended problem, conduct the experiments and present the outcomes **FI**: None
15: Teamwork	3	2	3	**TL**: Face-to-face meetings with the members improve the chance of better teamwork. **RDS**: Difficult to establish a functioning team or delays in some instances. **FI**: Potential to improve collaboration by changing the project and providing more time during the term.
16: Ethics in the Laboratory.	4	2	3	**TL**: Simple activities, so limited chance to do unethical work. **RDS**: Potential of sharing models between the teams. **FI**: Improved design of the project may reduce unethical work.
17: Engagement and learning	4	4	5	**TL**: More engaged with the lab activities. **RDS**: Less engaging with the laboratory activities but more profound learning. **FI**: Potential to improve engagement by changing the project activities.
Average score	2.6	3.1	4.0	

Laboratory Supervisor's Reflection

Traditionally, students attended the laboratory on campus and conducted the experiment assisted by the laboratory Supervisor. The students initially interacted with the equipment and the Laboratory Supervisor throughout the investigation. However, students followed the same process every year as outlined in the laboratory instruction guide. While the traditional practice benefited the student's understanding of engineering theory, the outcome and the data were the same every year.

The introduction of the modelling software HEC-RAS allowed the students to predict their expected outcomes before the actual remote laboratory session and gave them a sense of control over their experiment. The processes for conducting the new laboratory via Zoom were relatively straightforward for the Laboratory Supervisor and students. Open communication between the Laboratory Supervisor and the students allowed the students to dictate and manage the actual experiment. They selected the original modelled culvert design and flow rates and recorded the live data via Zoom. Notably, via communication with their laboratory Supervisor, the students also could complete repetitive testing on their specified culvert design, adjusting flow rates etc., in a short timeframe, facilitating a comparative analysis.

The new laboratory approach (Remote Design Studio) also allowed the students to interact with their team members and all teaching parties simultaneously (Unit Coordinator, Head of Course, and the Laboratory Supervisor). The new approach also significantly reduced student absenteeism, as all students could attend one of the online sessions.

Unit Coordinator's Reflection

In the traditional laboratory, students read the instruction guide on the experiments and would not necessarily have developed theoretical reasoning behind the phenomenon. However, students completed the simulation before the virtual experiment in the new approach. So, they were better prepared to provide scientific reasons behind the phenomenon, such as types of flow and the relationship of culvert properties to the upstream influx.

Every year a few students do not attend the laboratory due to health, family, or other issues and cannot complete the unit. No such problem arose this year. There may not be such issues this year, or because the laboratory session can be attended via Zoom, all students were able to participate.

During the informal discussion, many students mentioned that they favour the new approach and cited software as one reason. Some said they do not see any significant difference in attending the laboratory in person or via Zoom. However, a team of students living close to the university wanted to go to the laboratory in person for the experiments.

Five campuses previously offered a laboratory for distance and on-campus students. Scheduling laboratories on various campuses and coordinating with staff running the experiments was always a significant task in the previous years for the Unit Coordinator. The new approach reduced the workload, focusing on better learning outcomes than administrative work.

Generally, students make some comments (good or bad) at the end of the term through their unit evaluation if they perceive any activity is beyond their expectations. There was only one comment about the laboratory by the students, which implies they did not take the new approach as a surprise. The comment was about their confusion creating the report when the activity differs from the traditional method, which is unrelated to the new delivery concept.

Safety is one aspect missing in learning. Students previously completed a risk assessment and participated in the laboratory induction before the experiments. Due to the students watching the experiments via Zoom, there was no such opportunity, but these activities should be covered in other units.

Head of Course’s Reflection

We know that students value practical learning experiences but also the convenience of online learning. Undergraduate engineers naturally enjoy practical learning and often rate well-executed laboratory activities among their best experiences at university. However, with the increase in online learning, and the attraction to study at interstate or international institutions, we also know the cost of attending residentials and intensive laboratory classes can prohibit course progression.

In this study, we attempted to exchange a face-to-face practical activity with an online alternative introducing a design-based pedagogy centred on creating a digital twin as a hydraulic modelling and simulation tool with output verified by remote connection to a physical laboratory. Hence, introducing the Remote Design Studio concept. Our outcomes surpassed the objectives of an equivalent online scenario for practical learning by developing new skills in design, modelling software, and remote collaboration while also increasing students’ confidence in simulation outputs, which are crucial for producing job-ready graduates.

It is acknowledged that the Remote Design Studio did not demonstrate all laboratory objectives at a higher level, but this is not essential, considering other laboratory activities within the course are better suited to develop such skills. Overall, an improvement was achieved for staff and students. Hence, a broad update of this concept is recommended.

Discussion and Conclusion

The objectives for engineering laboratories were enhanced in this study before applying them to review a trial alternative to traditional laboratories by introducing the concept of Remote Design Studios. All staff and students reported that the trial was successful. Still, it was acknowledged that further improvements could be achieved and that it may not be appropriate to apply the new approach to replace all existing laboratory activities. The Remote Design Studio concept with digital twins did provide an effective method to engage students studying online and on-campus in practical learning and, in doing so, facilitated the development of work-ready skills. The Remote Design Studio concept can be applied to laboratory activities across disciplines where practical and technical competence is essential, and modelling and simulation tasks inform outcomes and create an enjoyable deep learning experience for students. Still, it is recommended that students complete the process over several weeks to obtain the greatest value from exposure to industry-standard software and their time remotely connected to the laboratory.

References

Anderson, L. (2006). Analytic Autoethnography. *Journal of Contemporary Ethnography*, 35(4), 373–395.

Brinson, J.R., (2015). Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research. *Computers & Education*, 87, 218-237.

Feisel, Lyle D., & Rosa, Albert J. (2005). The role of the laboratory in undergraduate engineering education. *Journal of Engineering Education* 94 (1),121-130.

Hernández-de-Menéndez, M., Vallejo Guevara, A. & Morales-Menendez, R., (2019). Virtual reality laboratories: a review of experiences. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, *13*(3), pp.947-966.

Holmes, W.N., (2010). The future of the computing profession. *Computer*, 43(7), 88.

Lal, S., Lucey, A.D., Lindsay, E.D., Treagust, D.F., Long, J.M., Mocerino, M. & Zadnik, M.G. (2020). Student perceptions of instruction sheets in face-to-face and remotely-operated engineering laboratory learning. *European Journal of Engineering Education*, *45*(4), 491-515.

Li, R., Morelock, J.R. & May, D., (2020). A comparative study of an online lab using Labsland and zoom during COVID-19. *Advances in Engineering Education*, *8*(4), 1-10.

Litzinger, T., Lattuca, L.R., Hadgraft, R. & Newstetter, W., (2011). Engineering education and the development of expertise. *Journal of Engineering Education*, 100(1), 123-150.

Viegas, C., Pavani, A., Lima, N., Marques, A., Pozzo, I., Dobboletta, E., Atencia, V., Barreto, D., Calliari, F., Fidalgo, A. & Lima, D. (2018). Impact of a remote lab on teaching practices and student learning. *Computers & Education*, *126*, 201-216.

Williams, D.J., Thomas, R.J., Hourd, P.C., Chandra, A., Ratcliffe, E., Liu, Y., Rayment, E.A. & Archer, J.R., (2012). Precision manufacturing for clinical-quality regenerative medicines. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 370(1973), 3924-3949.

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