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Off-campus but hands-on: Mail out practicals with synchronous online activities during COVID-19

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ABSTRACT

This paper discusses alternatives to on-campus teaching laboratories, to allow for hands-on learning for remote students. Wholly online practical equivalents have become increasingly popular post-COVID (online simulations or processing experimental data only) which can offer lower overheads and easy scale-up, but often miss hands-on learning outcomes. This paper reviews opportunities for mail-out practicals, where the equipment is delivered to students' homes, combined with live synchronous learning activities via video streaming or online software. The combination of mail-out experimental kits plus synchronous interactive learning activities creates a host of new opportunities for teaching to remote students. Complimentary online teaching activities could include direct interaction with teaching staff or other students, but it can also be real-time simulations of their experiment. The paper presents a specific case study for a 2nd year undergraduate chemical engineering heat exchanger practical, that facilitated hands-on practical learning with synchronous online activities during COVID-19 campus closure. The paper uses a mixed methods approach in a 2 year study to assess student learning outcomes.

1. Introduction and overview of issues and literature

Embracing online learning has opened a raft of new teaching pedagogies for tertiary education as well as a new economy of wholly online Universities and courses (Wallace, 2003, Tallent-Runnels et al., 2006). The trend towards greater online learning was accelerated in 2020 in response to widespread campus closures due to the COVID-19 pandemic (Marinoni et al., 2020, Nogales-Delgado et al., 2020, Park, Park et al. 2020, Qadir and Al-Fuqaha, 2020, Slamnik-Kriještorac et al., 2020, Bishop et al., 2021, Khant and Patel, 2021, Radzikowski et al., 2021). The need to rapidly backfill planned face-to-face teaching content with online or remote equivalents forced many academic coordinators into a reactionary mode: doing whatever worked. Many academics simply moved existing teaching activities online although the pedagogical design may never have been intended for an online class (Bangert et al., 2020). But there is now an opportunity to reassess all options and to be strategic about future teaching planning.

Teaching resources provided online (for example lecture notes, slides, video recordings, live lectures, tutorial sheets) are often expositive (providing information through instruction) (Gillet et al., 2001). Although expositive resources are an essential teaching tool, and form the pedagogical backbone of most University courses, many academic disciplines also require complimentary practice-based learning (for example laboratories, practicals, industry internships, site visits, clinical placements) to enable heuristic learning modes (allowing student to learn for themselves through 'doing'). There is increasing evidence that 'teaching by telling' alone is ineffective in STEM education (Freeman et al., 2014) and historically hands-on practicals have been considered essential for Engineering educational disciplines (Perrenet et al., 2000).

The move to online teaching modes has brought accompanying online equivalents for practicals and laboratories, that have replaced traditional 'hands-on' practicals (Glassey and Magalhães 2020). These online equivalent practicals offer new opportunities for active learning but also offer lower infrastructure overheads as well as greater flexibility and convenience to students. A 2018 internal survey of students at the University of Melbourne found that the primary reasons students cite for

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not attending face-to-face lectures are external barriers (such as long travel commutes to campus) (Wiseman et al., 2018); wholly online resources can remove these attendance impediments and so following campus closure, our department observed higher attendance in synchronous online lectures than in face-to-face lectures prior to 2020. Online teaching resources can also improve educational access for students with physical disabilities, family commitments, or for students overseas.

As online classes are usually free of physical space restrictions (particularly for virtual and computer-based practicals) there are no scheduling limitations; students are flexible to work when they want and for as long as they want (they are not restricted to specific timetabled windows of use). There are pedagogical advantages in allowing students to collect data over multiple days, analyse their results, realize their mistakes, and make experimental adjustments. Online teaching equivalents are also usually easier to scale up to larger class sizes.

The widespread use of online teaching equivalents during the COVID-19 pandemic, means there may be an increased student expectation of remote working equivalents post-pandemic. This doesn't signal the end of campus-based teaching formats but may suggest a new balance point between campus-based face-to-face learning activities and online learning equivalents.

1.1. Codifying terminology

Online practical equivalents can come in many different forms. One problem for academic discourse is that non-standardized terminology has often been used to describe online practical equivalents although recent attempts have been made to codify the technical vocabulary (Garrard et al., 2020).

1.1.1. Digital artefacts

In 2020, in an attempt to rapidly replace face-to-face practicals during COVID-19 campus closures, many coordinators relied on simply cutting any campus requirements from practicals but kept them otherwise the same (Garrard et al., 2020). For example, by distributing sample experimental data to allow students to conduct data-treatment only, but not permitting any hands-on experimental component. The practicals were not pedagogically designed to function in this way; it is only a product of administrative time constraints on academics during a rapid transition online.

In more strategic planning for online learning models, the academic literature has overwhelmingly focused on virtual practicals and remote practicals (Ogot et al., 2003, Hall et al., 2006, Koretsky et al., 2008, Aziz et al., 2009, Balamuralithara and Woods, 2009, Heradio et al., 2016, Glassey and Magalhães 2020).

1.1.2. Virtual practicals

These replace hands-on learning with a computer simulation, which students are able to interact with to collect information. Students input values and gather output data from an online simulation of a real-world problem. For example in Chemical Engineering, a common virtual practical utilises operator training simulator (OTS) software to recreate the operation of a control room in a chemical plant via a digital twin (Patle et al., 2014). These practicals are often highly simplified and designed to 'work'; they can remove problem-solving tasks required to trouble-shoot and may create a false impression of over-simplicity, unless specific trouble-shooting tasks are designed in.

1.1.3. Remote practicals

These allow students to remotely operate equipment on-campus but mediated through a computer interface. This could be by remote control (for example programming the movement of a robot/drone on campus) but it could also be by providing instructions to an on-campus staff member (a demonstrator or teaching assistant) who carries out the instructions of the students. So remote practicals can involve synchronous remote participation (if instructions are delivered in real-time) or asynchronous participation by proxy (if instructions are sent but carried out later by a staff member).

In all the models above, the practical experience of the off-campus student is mediated through a computer screen. They interact with a laptop, not a physical piece of experimental kit and so never come into hands-on contact. Despite the value that online practical equivalents can offer, they cannot provide all the heuristic learning value of hands-on practicals, that are essential to equip students with the capability to solve practical problems (Chen et al., 2019). There is evidence that hands-on experiments offer better practice-based learning outcomes (than digital equivalents) and high levels of student satisfaction (Bhathal, 2011, Larriba et al., 2021). There is also significant evidence that students do not learn in a single way; there are many different types of learners and so successful teaching practice is traditionally considered to cater to a variety of learning styles (Felder and Silverman, 1988). But hands-on practicals present a number of challenges in an off-campus learning environment.

1.1.4. Mail-out practicals

In distance education before the internet, it was common for students to be mailed simple practical rigs to conduct asynchronous experiments at their home (Long et al., 2012). The assignment could be completed by correspondence: mailed out laboratory kits could be accompanied with a manual or recorded videotape for instruction, the student could conduct experiments in their own time and then write up and mail in their report (Hoole and Sithambaresan, 2003, Hall et al., 2006).

Increased student connectivity online and improved hardware capabilities have facilitated innovations for virtual practicals and remote practicals and so engineering education literature has tended to focus on these specific practical modes (Ogot et al., 2003, Koretsky et al., 2008, Aziz et al., 2009, Balamuralithara and Woods, 2009, Heradio et al., 2016). But the traditional mail-out practical offers many new opportunities and innovations in a digital age, that are worth reconsidering (Larriba et al., 2021).

2. Overview of problem and opportunities

The ubiquity and familiarity of video-streaming software post-COVID has facilitated new opportunities for mail-out practicals to be conducted *synchronously*. Prior to 2020, it was far more common to run asynchronous mail-out practicals, where manuals or instructions were provided as separate resources (pre-recorded videos, lab manuals) (Walkington et al., 1994, Hall et al., 2006). Some practicals may have run with synchronous audio-only instruction over the phone (although no examples could be found in an academic literature search). Today, educators can ship equipment to students' homes, then run synchronous live classes over video-conferencing software. Students can interact with the equipment and engage in live discussion with teaching staff via a video stream: equipment can be seen over video, not just described; students can interact with each other or teaching staff directly to ask questions on the spot; demonstrators can better supervise student's work and safety; there are greater opportunities for active learning (in the off-campus environment); synchronous hands-on components can be fully integrated with online simulations.

Online interaction doesn't need to be limited to video conferencing with other students or teaching staff. It could also involve live simulation of a parallel virtual practical (a digital twin) with predictive outputs from the hands-on practical. There are a wide variety of virtual learning activities to compliment hands-on experimental kits.

The rise of the secondary sector of the economy in China and ease of connecting to speciality suppliers via online purchasing platforms has lowered the cost of equipment. Experimental kit like soldering stations, ELVIS boards or process equipment (pumps, heaters, sensors, valves) have come down in cost in relative terms. Some Universities have 3D printed experimental components in-house (Larriba et al., 2021). These developments make it easier than ever before to have multiple kits that can be sent to each student, or a collection of kits that can be rotated between students on a week-to-week basis.

2.1. Off-campus (vs on-campus)

On-campus activities allow for greater control of the teaching environment; this can mean a greater degree of student safety (for an equivalent practical) or the use of more hazardous equipment or chemicals (for the same level of safety). Shipping time, size and weight costs can restrict what can reasonably be mailed to students and so on-campus practicals offer the opportunity for larger scale equipment. However off-campus practicals have fewer scheduling and timetabling constraints; students are afforded greater flexibility to collect data over multiple sessions. Off-campus practicals were a necessity during the COVID-19 pandemic, but may also offer students greater accessibility (due to travel restrictions, travel times or physical barriers such as disability). However, depending on the size and nature of the equipment sent out, not all students may be in a position to run these experiments at home. Inclusivity is a multi-faceted issue and must be considered in all teaching activities.

2.2. Synchronous (vs asynchronous) mail-out practicals

Asynchronous mail-out practicals can offer lower ongoing teaching overheads and greater scalability; subject coordinators can create a single lab manual or instructional video and then scale up to larger class sizes, where synchronous practicals require more demonstrator or coordinator time as student enrolments increase. Synchronous practicals offer the opportunity for direct feedback and interaction with teaching staff; this can be particularly important in open-ended laboratory design, where students need to ask questions to facilitate active learning discussions. Synchronous practicals also offer greater safety as students are supervised during video-conferencing and have the opportunity to query any uncertainties (there is less opportunity for misunderstanding from prewritten instructions).

3. Discussion of implementation: heat exchanger practical case study

The University of Melbourne ceased all face-to-face teaching on the 24th March 2020 due to the COVID-19 pandemic. It soon became apparent that we may not return to campus teaching for some time and so on-campus practicals would need to be replaced with off-campus equivalents (Nogales-Delgado, Román Suero et al., 2020). From this standing start, we began planning and then construction of new mail-out practicals with synchronous video-conferencing interaction and other complimentary online activities, for semester 2 2020.

The practical was for a 2nd year Chemical Engineering subject (Chemical Process Analysis, CPA) to develop an understanding of heat exchangers, basic processing equipment and economic/operational feasibility within a milk processing facility, in a problem-based learning design (Mills and Treagust, 2003).

In 2020 we collected survey results and student feedback on the teaching efficacy of the practical, then refined the practical and repeated it in 2021 (our city was still in lockdown at this time). So the work here represents 2 years of results.

3.1. Primary objectives of the practical

We set 3 primary objectives for the new practical:

1. **Learning outcomes.** We wanted the practical to be an effective tool for developing students' knowledge, practical skills and critical thinking:
    11. *Hands-on practical learning.* Among a wide range of practical engineering skills this would include: 1. learning how to cross-tighten bolts (here in a flange to provide an even seal to stop leaks but this is also applicable to changing a car tyre); 2. how and why to prime a pump (we do a dry start for comparison); 3. how fluid head provides pressure; 4. how and why to calibrate basic equipment (flow meters, thermocouples); 5. Assembling a basic flow kit; 6. how and when to use basic hand tools (shifting spanner, torque wrench); 7. how to tighten a bolt/nut (right hand rule for tightening, understanding that over-tightening can strip a thread).
    12. *Theoretical subject content.* Instruct students in the design and theory of a heat exchanger. This involves application of energy balances (first law of thermodynamics) and conductive heat transfer calculations (Fourier's first law) to estimate heat losses to the environment and derive the overall efficiency of a heat exchange.
    13. *Applied subject content.* The subject introduces basic processing kit and its practical implementation: pumps, valve types, flow meters, thermocouples, piping, flanges, bolts and tanks. For example: how to sequence flow meters and valves (flow meters are usually placed before control valves to prevent disturbance in the measurement); where to place thermocouples (usually as close to the desired measurement point as possible to minimize thermal losses); whether to rely on the suction or outlet pressure of a pump; how to check for cavitation onset by comparing inlet pressure and vapour pressure. Students are also introduced to Australian Standards for design.
    14. *Developing critical thinking.* A common misconception is that problem-based learning automatically develops students' independent critical thinking (Masek and Yamin, 2012). However specific teaching strategies need to be embedded within problem-based learning models to develop these skill-sets (Ahern et al., 2019).

2. **Social outcomes**. Campus closures in 2020 created barriers to cohort building from informal social interaction: meeting peers between classes, socializing in free periods, interacting on campus. These social networks are important both for professional development (engineers are required to learn to work effectively in teams), for industry networking (University peers form a graduate's first professional network) and from a student wellbeing perspective. Meaningful friendships have been shown to improve students mental health (Eisenberg et al., 2007, Vogel et al., 2007) improve overall satisfaction in University studies (Hendrickson et al., 2011) and are important for creating feelings of connectedness, inclusion and adjustment to campus life (Buote et al., 2007).
3. **Safety**. It was imperative that the practical was conducted safely in the off-campus locations to protect students. But these safety discussions also functioned as a direct learning experience by following industrial OH&S requirements and embedding safety expectations within the cohort.

3.2. Apparatus

The kit mailed to students contained: A plate heat exchanger, a centrifugal pump, a tank reservoir, 4 x thermocouples mounted into pipe fittings, 2x flow sensors mounted into pipe fittings, 2x gate valves, various hose fittings (to fit to a variety of taps) and an assortment of piping with bolts, olives and nuts to build a fluid circuit. The kit also contained basic hand tools to assemble the rigs, Teflon tape for sealing, safety glasses, hand-sanitizer and wet-wipes for equipment cleaning after use. It could all be disassembled and packed into a container of 410 mm x 425 mm x 660 mm and weighing 22 kg. Ordering parts and building the rig took approximately 4 weeks and was completed almost immediately following the University closure.

Seven rigs were built and rotated between students, with each student having the rig at their home for 5 days. The rigs were couriered directly between student's homes (the equipment did not return to campus between remote destinations). One complete set was kept on campus in case of equipment failure; there was some wear-and-tear on the equipment as it moved between students, but there was no major critical failure that required a replacement kit.(See Figs. 1–3).

3.3. Procedure

Students were first asked to complete a survey to confirm that they had sufficient facilities at their home to host the practical safely (space to work, an appropriate tap fitting, a power source for the pump, a first aid kit and a second person at their home in case of emergency). We provided the equipment to any shipping destination within Australia but did not ship it internationally as we could not deliver it within a reasonable time.

Students were assigned by the subject coordinator into small teams (the teams are not self-selected). Students completing the hands-on component of the practical were given the role of 'Process Engineer' and distributed evenly among the groups. Students who would not complete a hands-on component were given a complimentary role of 'Simulation/Design Engineer'. Students were able to select between the 2 roles, if they had sufficient facilities at their home to host the practical (sufficient space, access to a tap, access to a drain), but if they could not host the prac, they were assigned as a simulation/design engineer. The simulation/design engineer role was fully integrated into the hands-on practical to provide a synchronous group-based problem, and was designed to simulate real working conditions where different engineers perform specialized roles. While the process engineer managed the experiment, the simulation/design engineer recorded values, calculated efficiency results in real time and updated a predictive HYSYS simulation of the heat exchanger (based on ambient and inlet temperatures and flowrates). As such, the virtual students were fully integrated into a synchronous learning environment and could comment on experimental errors, trends and the validity of final results immediately, to identify the need for additional data collection (or possible errors). Hands-on and hands-off roles were complimentary and interwoven to encourage collaborative working and discourage sub-division of the group tasks. Simulation/design engineering roles also completed a piping and instrumentation diagram of the layout and validated the equipment specifications against Australian Standards for milk processing (AS-3993). Although students would submit a single group report, they also completed a declaration sheet at the start (indicating who had contributed what to the final report, where roles overlapped) to decouple grades into individual marks.

Fig. 2. Disassembled experimental kit in shipment pack.

The experimental rigs were couriered directly to students. Before beginning any experimental work, students were required to complete a Take-5! risk assessment to identify any hazards in the workspace, which was submitted electronically to the demonstrator. Using prompts in the lab manual, student groups were required to identify experimental risks as an engineering safety moment. The groups then met with the lab demonstrator for 45 mins via Zoom to discuss the use of the equipment. (All meetings described here were held via video conferencing.) This

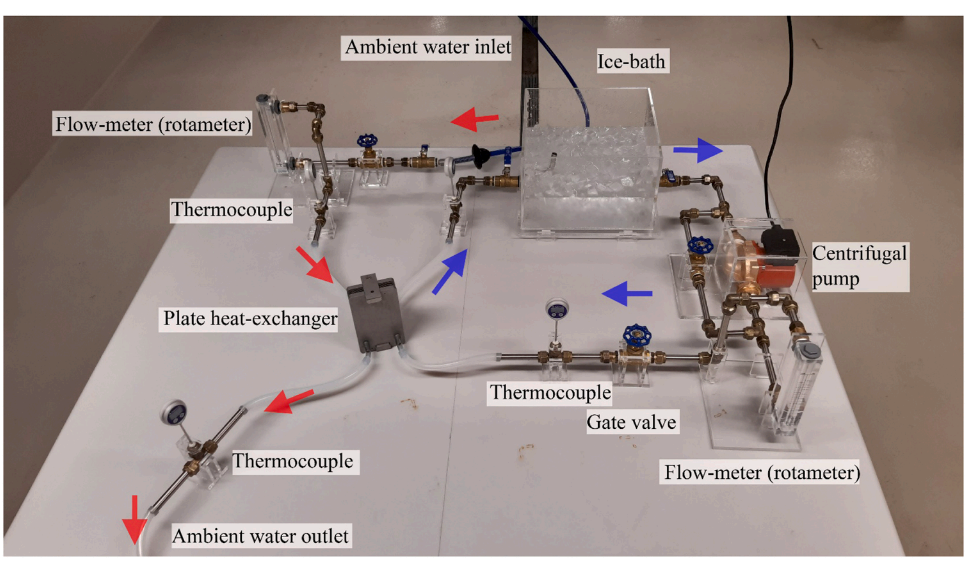


Fig. 1. Assembled equipment in one possible configuration. Flow directions for ambient temperature water (red) and iced water (blue) are shown with equipment labels. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

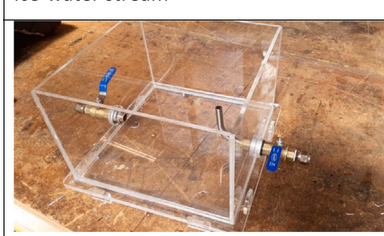
 100 mm long steel pipes (x20) – used to assembly the rig. These come with fitted olives and nuts.	 Spare olives (x10), nuts (x10), knees (x2) and unions (x2)
 Spanners (x2) and a flat head screwdriver (x1)	 Safety glasses. Multiple sets were included to reduce COVID-19 transmission risks
 Connectors between your water hose and the rig (x3). Compatible with hose sizes (from left): 12 mm, 13 mm and 18mm.	 Gate valves (x2)
 Flow meters (x2)	 Thermometers (x4)
 Water pump (x1) – used to circulate the ice-water stream	 Electrical extension (x1) – used to connect the pump
 Ice-water tank (x1)	 Either tube (left) or plate (right) heat exchanger (x1)

Fig. 3. Inventory of equipment included in mail-out practical.

meeting facilitated a visual inspection of their workspace by the demonstrator and covered a safety checklist including: ergonomic risks (tripping over cables, dropping heavier equipment) as well electrical risks (keeping power boards or electrical plugs elevated from ground water spills). At this meeting, students would turn on the pump for the first time under the live video-streamed supervision of the demonstrator. They tested a dry start (to learn about how and why to prime the pump) then conducted a proper primed start. It was common for fittings to be improperly sealed (causing a leak) which were discussed with the demonstrator (how to get a good seal, the importance of Teflon tape, how to cross-tighten a flange, how not to cross-thread a nut).

The group then met again to discuss the learning outcomes from the demonstrator meeting and develop their experimental protocol. The lab manual instruction and demonstrator meeting focused on correct use of the equipment but avoided specifying a specific flow configuration for the testing rig or prescribed experimental methodology. Students were instead required to discuss and develop their own testing protocol (setting flowrates, insulation requirements, counter-current-/co-current flow configuration) as well as the experimental layout, to determine the end goals set by the assignment sheet (determining the heat exchanger efficiency in different flow configurations).

Students then met with the subject coordinator to present their proposed experimental methodology and to discuss safety in a 45 min 'academic defence' over Zoom. This was assessed to 5% of their final subject mark. The phrase 'academic defence' implies an attack, but the tone of the meeting was very collaborative and supportive. The subtext of the meeting was "we're trying to develop a solution to the problem together". Discussion in the academic defence followed the Socratic method of teaching (Delić and Bećirović 2016) where the instructor tries to probe students with questions that lead them to their own conclusions, rather than providing prescriptive instruction. Students presented their method and the instructor asked questions, to help students identify and then solve possible limitations; the instructor did not declare a method right/wrong or require a step to be done. As an instructor, this can be difficult as it sometimes means allowing students to develop methods that you don't believe will work. We would only have intervened with explicit instructions if they proposed to do something that was unsafe.

After the academic defence, student groups were free to proceed with the agreed experimental methodology. They had ongoing access to the subject coordinator and demonstrator over the following 5 days until the experimental rig was couriered to the next student. During this time, students could conduct experiments as many times as they wanted, often iterating on their experimental methodology as they discovered heuristically that some initial assumptions or experimental designs may not work.

After concluding their experimental work, students completed a group practical report and submitted it online for a 15% total weighting to their subject grade. Students were also asked to comment on the economic feasibility of installing the heat exchanger in a milk processing facility, based on their efficiency calculations and simple capital and operating expenses.

3.4. Additional safety considerations

The continuous supervision by a demonstrator in on-campus labs is made more difficult in the off-campus environment. So, most of our initial faculty OH&S review process focused on improving supervision and intrinsic safety. Preparation for the demonstrator was thus different to a normal practical, where they needed to be confident with the laboratory equipment itself, the technical platform to host the practical (Zoom), as well as instructing students to direct camera motion to visually confirm all safety requirements of the practical (ie managing people in physical space on the other end of the meeting).

Similar to other mail-out chemical engineering practicals, we made water the only working fluid (Larriba et al., 2021). In the initial design, we planned to heat a water stream to 60 °C in a temperature bath with an electric heater. But the possibility of over-heating the water or directly touching the heating elements created a safety risk that we mitigated by using an ice-water bath to create a temperature difference; students bought ice at a local supermarket and put it into the ice water tank. The counter stream in the heat exchanger is ambient temperature water from a tap. Electrical risks were mitigated by containing the pump is a sealed box (both to prevent water leaking into electrical components and to stop students from tampering with the pump casing). Approved extension cords were included in the experimental pack to discourage students from using any untested extension cords or power-boards.

Students completed the experiments in groups with a hands-on process engineer role and complimentary simulation/design engineer role over Zoom. As well as integrating the 2 roles into the problem-based learning exercise, this also provided an important extra layer of safety: there was always a second person present (in a virtual capacity) during the practical, so in the event of an accident, they could alert emergency authorities. This requirement was discussed in initial safety planning with students.

3.5. Insights from other mail-out practical case studies

In very good and parallel work conducted during 2020 campus closure, Larriba et al. also identified the value of at-home practicals for chemical engineering students (Larriba et al., 2021). They conducted heat transfer experiments with 3D printed vessels and measured temperature change with alcohol thermometers. They have generously provided accompanying resources as open access and a major advantage of their practical design are low costs per student (12.5€ in parts plus shipping and staff time to arrange). This is a very innovative practical, but the focus of our practical was to develop familiarity with real-world equipment. So, although the taught concepts are similar (heat transfer calculations) the practical designs were significantly different: our rig included pumps, thermocouples, flow-sensors, valves and pipe fittings. The material costs of each rig were $AUD 1028 plus staff time to arrange (approximately 50–60 hrs to organize, develop manuals and build). This cost was born by the University and the rigs were rotated between students with a shipping cost of only $20 for metropolitan areas (or $100 for regional areas), so development and construction costs were a single upfront cost. In both case studies, it is likely the staff time to organize the practical is the major cost.

Item	Cost per rig ($AUD)
Shipping Box	18
Pipe lengths	10
4 x digital thermocouples	140
1 x pump	130
2 x flow meters	90
2 x T-connectors	20
3 x gate valve	120
2 x ball valves	30
Acrylic (for stands and tank)	250
Connectors	220
Total	**1028**

4. Discussion of impact

4.1. Methodology employed to measure impact

Our primary research question was to assess the 'success' of the practical. But for our practical design, success came across 3 separate domains for learners: 1. Enhanced learning outcomes, specifically kinaesthetic and practical learning under remote conditions; 2. Promotion of social connectedness within the cohort during remote study and 3. Safety- the practical must still be conducted safely while working remotely to be considered a success, although no incident may have occurred. So the broad nature of the 3-part research question suggests an exploratory mixed-methods approach. We developed the method and collected results over a 2 year period. The exploratory mixed methods approach included:

1. Following conclusion of the practical in 2020, a small focus group was held with learners. This was essentially an informal discussion between the subject coordinator and student group, focusing on learning outcomes, social connection and safety; it was designed as a qualitative exploratory study to gather feedback.
2. The outcomes from the focus group were used to inform the development of a survey instrument which contained 22 separate questions (and one open-ended response question) directly addressing the 3 key domains within the research question. The survey instrument contained a series of prompt statements with a 5-point Likert scale response consistent with established survey practice, to enhance the data's validity (Johns, 2010, Joshi et al., 2015). These survey questions were not the research questions, but were questions designed to generate data that could be used to help inform answers to the research questions. The survey was designed to ask multiple versions of a question within a single domain of the research question, to help test the reliability of the responses (for example asking students to respond to the statements "The group work in the CPA practical helped build a stronger cohort experience with other students in the class" and "The CPA practical helped me make 1 new friend in the class that I had not met previously"). The survey was tested with a small group of users (academics and students) to proof read for clarity and coherence. These were done under the supervision of the lead researcher (to make sure test respondents were responding to the questions as intended). These test survey results were not used in the final study. This step helps verify the validity of the survey instrument, to ensure questions are interpreted as intended.
3. The survey was distributed to all students in 2020 cohort (we had a 45% response rate, n = 41, 11 were process engineer roles, 23 were simulation/design engineer roles and 7 chose not to identify their role in the survey but completed all other components).
4. The practical was repeated again in 2021 and students completed the same survey (with a 58% response rate, n = 34, 13 were process engineer roles, 15 were design/simulation engineer roles and 6 chose not identify their role in the survey but still completed all other questions). There were minor modifications to the practical between 2020/21 as we made iterative improvements, but the practical design was ostensibly the same (still a mail-out practical with an open-ended structure). Repeating the survey across 2 years provides a mechanism to confirm the reliability of the survey responses between years. The results between years agreed within very high precision; in most cases, Likert scores were within 0.03 margins and the largest Likert score deviation between years was 0.27 (for statement 4.1.1.4) although this is still within the standard deviation of responses within a single year. The responses of process engineer roles and simulation/design engineer roles agreed within measurement error (the standard error) unless addressed specifically within the discussion.

4.2. Results and discussion

Our primary tool for interrogating our research questions are student's self-assessed perceptions of learning outcomes, which are compared to other data where possible (for example aggregated subject grades, related studies, anecdotal accounts). But there are methodological limitations with student's self-assessment of learning outcomes: 1. There is sometimes a mismatch between students' self-assessed competency and performance in objective measures such as subject assessment (McCourt Larres et al., 2003). For example in a previous study, first year undergraduate students tended to over-estimate their computer-literacy in new classes (Ballantine et al., 2007) and self-assessment in lower level courses tend to deviate further from coordinators assessment (here our study is conducted at second year undergraduate) (Falchikov and Boud, 1989). What we have measured are *perceptions* of learning, safety and cohort-experience, rather than independent and objective measures of these outcomes.

Like many other teaching-practice researchers, we use our own class for evaluative feedback on new teaching initiatives. A problem with this method is that typical class sizes, with low voluntary response rates can create small sample sizes. In the current study, the subject had 92 student enrolments in 2020, with a 45% response rate to the voluntary survey (n = 41). Then in 2021, we had 59 student enrolments in the subject with a 58% response rate (n = 34). So to more reliably test our conclusions, we also compare our findings to related complimentary studies that have performed similar research. The comparison can help validate our own results and the results of complimentary studies, by providing a larger and more diverse sampling.

To maintain privacy and elicit more honest responses, we did not collect identifying data about students (name, identity, student number) but we did collect their role within the experiment: process engineer or simulation/design engineer. So this allows us to test the experiences of the 2 cohorts: are their experiences equivalent? Students responded to statements on a 5-point Likert scale (strongly agree, agree, neither agree nor disagree, disagree, strongly disagree) (Joshi et al., 2015). The results are presented as an average Likert score, a standard deviation in Likert score and a percentage of students who agree with the statement (percentage of respondents who agreed or strongly agreed).

4.2.1. Overall learning outcomes

In student self-assessment, the practical performed well in a general statement of learning experience (4.2.1.1). Students expressed a preference for synchronous mail-out practicals to continue if the campus remained closed and rated the practical more favourably than wholly online replacements (4.2.1.2 and 4.2.1.4). The mail-out practical rated poorly when compared to traditional face-to-face practicals on campus (4.2.1.3) that students had completed previously. However, practicals running on campus have had many years to be refined without highly restrictive time constraints. Also, not all students were able to complete hands-on components of the practical; some adopted hands-off roles of simulation/design engineer. We anticipate further improvement in future iterations and note that this is not a directly equivalent comparison.

This is also a difference observed between the learning experience of the hands-on process engineer role and hands-off simulation/design engineer role. In all 4 question categories, the students completing hands-on components rated their experience more favourably. Although the results often lie within 1 standard deviation, the more favourable rating provided by the process engineer roles is consistent across all 4 question domains (this implies a systematic difference, not a random difference). It might seem intuitive that the students completing the hands-on component of the practical would have a more favourable experience of it; the results indicate this as well. But we also observe that students were able to self-select into the process engineer role (if students had facilities at home to complete the hands on component, they were given the choice to do it). So it's also worth observing that this role may have self-selected higher performing students who were naturally more engaged in the learning exercise (students who self-selected into the process engineer role had higher weighted average marks coming into the subject).

4.2.1.1 Overall, the CPA practical was a useful learning experience for me (including both practical and theoretical components of the assignment)	Likert Average Score Process Engineer Simulation/Design Eng Standard Deviation % Agree	4.294.693.93 0.81 89%
4.2.1.2 If I am unable to attend campus next semester, I would	Likert Average Score Process Engineer Simulation/Design Eng	4.214.693.80

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like the option to complete more mail-out practicals.	Standard Deviation % Agree	0.92 82%
4.2.1.3 The CPA mail out practical provided a better learning experience than traditional face-to-face practicals I have done on campus. *Student had the option not to answer if they had not previously completed a practical on campus	Likert Average Score Process Engineer Simulation/Design Eng Standard Deviation % Agree	2.713.202.25 0.12 29%
4.2.1.4 The CPA mail out practical provided a better learning experience than a wholly online assignment.	Likert Average Score Process Engineer Simulation/Design Eng Standard Deviation % Agree	4.394.804.07 1.12 93%

The final lab reports were marked by the same demonstrator in 2019 and 2020 (we had a new demonstrator 2021). We used the same grading rubric and set the same expectations between years, although the specific design of the practical changed over that time. The final grades showed a dramatic improvement between years with the introduction of the new mail-out practical.

2021 final lab report mark: 76.9/100 (n = 58) 2020 final lab report mark: 76.3/100 (n = 92) 2019 final lab report mark: 63.2/100 (n = 96) (old lab- baseline).

These grades conflate a range of different effects: long lockdowns in Melbourne, remote working conditions throughout 2020 and 2021, a different cohort of students between years. As such, the improved assessment performance cannot be solely attributed to the changes to the practical design; it conflates many environmental effects that cannot all be controlled for. It is only an indirect indicative result to help support the findings of the improved learning outcomes self-reported by students; the 2 results are internally consistent, which helps validate the data.

Comparing our results to another at-home heat transfer practical by Larriba et at. (Larriba et al., 2021) we see similar levels of student satisfaction. In their study, assuming students were confined to their home, 43% of respondents preferred a lab at home, 13% preferred a data treatment (digital artefact) and 36% preferred an online simulation (8% preferred no replacement activity, n = 84). Although the experimental designs are quite different, it indicates high levels of student satisfaction and preference for hands-on mail-out practicals. Our results affirm their key findings.

Finally, an anecdotal observation: Both the demonstrator and subject coordinator had student's parents join our Zoom meetings with the student groups, to thank us for arranging the mail-out practical. We also received a lot of positive feedback both verbally and in written evaluative survey comments at the end of the semester from students. This does not demonstrate improved learning outcomes, but it was indicative of a positive sentiment about the lab experience overall.

4.2.2. *Critical thinking and deeper learning*

A key initial design of the practical was to enable critical thinking by providing a non-prescriptive assignment brief. Students were asked to assemble the testing rig in their own configuration and design their own experimental steps. They were required to present their experimental proposals to a lab demonstrator and subject coordinator in two 45 min meetings (and were assessed to 5% of the subject grade overall in the meeting with the coordinator in an academic defence).

Student self-assessment of this deeper learning design was generally positive. The non-prescriptive instructions of the lab (tested in Q 4.2.2.1 and Q 4.2.2.4) both received strong agreement with the statement that it enabled students to think more deeply about the experiment (which also suggests reliability of the result). The meetings with teaching staff, which focused on students presenting their ideas and being critically interrogated in a Socratic teaching method, also received stronger positive feedback.

All results here showed a high concordance between process engineer roles and simulation/design engineer roles (within a Likert score of ± 0.2) except question 4.2.2.1, which showed a more marked difference in self-reported experience (but still within the standard deviation of the result).

4.2.2.1 The non-prescribed lab brief in the CPA practical helped me think more deeply about the experimental method (than a prescribed lab brief)	Likert Average Score Process Engineer Simulation/Design Eng Standard Deviation % Agree	4.294.624.0 1.12 89%
4.2.2.2 The meeting with the lab demonstrator was a useful learning experience for me.	Likert Average Score Standard Deviation % Agree	4.15 1.12 85%
4.2.2.3 The assessed meeting with the Subject Coordinator (Chris Honig) was a useful learning experience for me.	Likert Score Standard Deviation % Agree	4.43 1.12 96%
4.2.2.4 Being able to assemble the testing rig ourselves and use different configurations, helped me think more deeply about the experiment.	Likert Average Score Standard Deviation % Agree	4.14 1.12 93%

4.2.3. *Multiple and prolonged access to equipment*

Remote practicals do not require scheduled times in wetlab teaching spaces, so a key learning design in initial planning was to encourage iterative experimental collection (to enable deeper critical thinking). Students could 'play' with the rig and collect data over multiple sessions, refining their experimental design based on previous results. One problem was the practical used a consumable bag of ice for a water bath, meaning successive experiments required replacement ice; this added time to organize and additional expense to students, which may have discouraged iterative experimental attempts. Student experiences between process engineer and simulation/design engineer roles were not significantly different.

4.2.3.1 Having access to the rig for several days and being able to collect data helped improve my understanding of the practical (as opposed to a single 3 hr lab session)	Likert Average Score Standard Deviation % Agree	3.82 1.12 71%

The option for extended experimental access was generally rated positively for learning outcomes (4.2.3.1) although only half of the cohort collected experimental data in more than a single session (4.2.3.2).

	Response	Percentage
4.2.3.2 How many separate sessions did your group use to collect experimental data?	1 (we collected all data in 1 session)	53%
	2	25%
	3	18%
	4	0%
	5 +	4%

4.2.4. *Student cohort building during lockdown*

The closure of University campuses and transition online restricted opportunities for student socializing. So a key focus for this practical was to embed cooperative tasks to facilitate socializing around the practical as an ice-breaker activity, to create space for cohort building online (Conrad, 2005). The learning activity was gamified (Cheong, Cheong et al. 2013, Subhash and Cudney, 2018) to create a common problem as a point of interaction, like a recreational group puzzle game: an escape room, playing dungeons and dragons or cooperative video-gaming. Students were grouped into small teams with each one given a specific role: process engineer (handling the equipment, collecting experimental results) or simulation/design engineer (completing a HYSYS simulation and energy transfer calculations in real time). No one role could complete the assignment alone; the work could not easily be subdivided and all roles had to work together to complete the task.

Student self-assessment of the cohort building in a range of different prompt statements, were overall very encouraging. Perhaps of most surprise was the response to Q 4.2.4.3 "I would prefer to have no group work and complete all assessment individually" only had an 3.6% rate of agreement; anecdotally many students seem to bemoan group work in subject written feedback, but here it was rated very positively. This result alone cannot be used to prove good design of group-work in the practical as it convolutes a range of other environmental factors. For example students may have been starved for opportunities to interact with peers following a prolonged pandemic lockdown in Melbourne. It is an encouraging result but does not constitute definitive proof of good socialization through the practical. The social cohort experiences of process engineer and simulation/design engineer roles were not measurably different.

4.2.4.1 The group work in the CPA practical helped build a stronger cohort experience with other students in the class	Likert Average Score	4.04
	Standard Deviation	1.12
	% Agree	82%
4.2.4.2 The CPA Practical helped me make 1 new friend in the class that I had not met previously	Likert Average Score	3.93
	Standard Deviation	1.12
	% Agree	86%
4.2.4.3 I would prefer to have no group work and complete all assessment individually.	Likert Average Score	2.25
	Standard Deviation	1.12
	% Agree	3.6%
4.2.4.4 I enjoyed working with my lab group and it was an enjoyable experience overall.	Likert Average Score	4.04
	Standard Deviation	1.12
	% Agree	85%

4.2.5. Safety

Given the practical was completed remotely without constant supervision, it was important to induct students and complete online inspections of their work area. In self-reported feedback, the overwhelming majority of students felt the level of training was appropriate, a small minority felt it was excessive. No students reported feeling the training was insufficient and no difference was observed between hands-on/hands-off cohorts.

	Response	Percentage
4.2.5.1 How would you rate the level of safety training provided prior to the practical?	The level of safety training was appropriate	94%
	There was excessive safety training	6%
	There was insufficient safety training	0%

5. Conclusion

Instructional teaching is useful, but many academic disciplines continue to require complimentary hands-on learning for effective education. Wholly online teaching equivalents have become increasingly popular for teaching off-campus students: digital artefacts that replace practicals; virtual practicals that are wholly online simulations; remote practicals that allow for remote control of on campus equipment. But all these teaching methods mediate students' education through a computer screen. Mail-out practicals offer the opportunity for direct hands-on learning. When combined with new remote teaching strategies (such as live synchronous interaction with teaching staff via video streaming or online simulation of their physical practical) a range of new possibilities are opened for remote education. This paper outlines a specific case study of a mail-out practical for a 2nd year chemical engineering class. The practical utilizes a range of interactive and synchronous online activities to better engage students' critical thinking, improve learning outcomes, embed hands-on learning skills, integrate a strong safety culture and to improve students' social and cohort experience during campus closure. Student self-reported learning outcomes of these pedagogical strategies indicate they were successful, and there was a significant improvement in students' academic performance. The intersection of mail-out practicals and synchronous online activities offers a promising nexus for future remote education curriculum design.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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