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Article:

Choate, J, Aguilar-Roca, N, Beckett, E et al. (7 more authors) (2021) International educators' attitudes, experiences, and recommendations after an abrupt transition to remote physiology laboratories. *Advances in Physiology Education*, 45 (2). pp. 310-321. ISSN 1043-4046

<https://doi.org/10.1152/advan.00241.2020>

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1 **International educators' attitudes, experiences and recommendations after an abrupt**
2 **transition to remote physiology laboratories**

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5 **Running head:** Educators experiences of remote physiology laboratories
6

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23 **KEYWORDS:** laboratory; virtual; remote; COVID-19.

24 **ABSTRACT**

25 The COVID-19 pandemic triggered university lockdowns, forcing physiology educators to
26 rapidly pivot laboratories into a remote delivery format. This study documents the experiences of
27 an international group of ten physiology educators surrounding this transition. They wrote
28 reflective narratives, framed by guiding questions, in order to answer the research question
29 *‘What were the changes to physiology laboratories in response to the COVID-19 pandemic?’*
30 These narratives probed educators’ attitudes towards virtual laboratories before, during and after
31 the transition to remote delivery. Thematic analysis of the reflections found that before COVID-
32 19, only a few respondents had utilized virtual laboratories, and most felt that virtual laboratories
33 could not replace the in-person laboratory experience. In response to university lockdowns, most
34 respondents transitioned from traditional labs to remote formats within a week or less. The most
35 common remote delivery formats were commercially available online physiology laboratories,
36 home-made videos and sample experimental data. The main challenges associated with the rapid
37 remote transition included workload and expertise constraints, disparities in online access and
38 workspaces, issues with academic integrity, educator and student stress, changes in learning
39 outcomes and reduced engagement. However, the experience generated opportunities including
40 exploration of unfamiliar technologies, new collaborations and revisiting the physiology
41 laboratory curriculum and structure. Most of the respondents reported planning on retaining
42 some aspects of the remote laboratories post-pandemic, particularly with a blended model of
43 remote and on-campus laboratories. This study concludes with recommendations for physiology
44 educators as to how they can successfully develop and deliver remote laboratories.

45

46

47 **INTRODUCTION**

48 *COVID-19 pandemic and the need to transition from on-campus to remote teaching of*
49 *physiology laboratories*

50 The spread of COVID-19, caused by the severe acute respiratory syndrome coronavirus 2
51 (SARS-CoV-2), was declared a pandemic on 11th March, 2020 (39). In response to the COVID
52 pandemic, university leaders reacted to rapidly evolving information and government
53 restrictions, making critical decisions that impacted undergraduate physiology education,
54 particularly for laboratories. Many governments restricted the movement of people and
55 introduced physical or social distancing requirements, to help prevent the spread of the virus.
56 This resulted in university educators working from home, with prohibition of access to physical
57 laboratories, precipitating an urgent need to implement remote learning arrangements for
58 laboratories. Many physiology educators were forced to abruptly pivot a laboratory course that
59 had traditionally been on-campus and in-person (i.e. face-to-face or ‘live’) to a remote
60 (predominantly virtual) format. Normally, a successful transition to virtual delivery involves
61 planned, systematic, time-consuming and collegial design of the content and development of new
62 skills (30). With a rapid transition to remote laboratories, most of these processes were not
63 possible, particularly the availability of support staff and resources. Hence, a COVID-induced
64 expression ‘Emergency Remote Learning’, which acknowledges that this process was quite
65 different from the ‘normal’ planned online learning experiences (36).

66

67 *Context of physiology education: what are laboratories?*

68 The opportunity for students to engage in hands-on laboratory work is considered an essential
69 component of physiology courses or degree programs. Laboratories provide a unique learning
70 environment that not only facilitates scientific discovery and develops technical familiarity, but
71 also reinforces students' knowledge and understanding of physiology concepts and provides
72 opportunities for students to develop research skills (e.g. experimental design, data collection,
73 analysis and interpretation) and transferable, or employability, skills (e.g. critical thinking,
74 communication, resilience, problem solving and team-work) (16, 23). Furthermore, laboratories
75 enhance student engagement, thereby supporting the social constructivist theory of learning (20).

76

77 Laboratories are traditionally taught on-campus, with in-person sessions in a laboratory setting.
78 In addition to the faculty or academic lead teaching the laboratory, teaching associates or
79 assistants (TAs), also called PhD demonstrators or demonstrators, facilitate the teaching of
80 physiology laboratories and support students as they complete their experiments. TAs have
81 conceptual knowledge and technical skills for the laboratories and may be graduate or higher-
82 level undergraduate students. At some universities the graduate TAs are the lead, or independent,
83 instructors for the laboratory. Whilst acknowledging that there is variability across universities
84 for the terminology and type of teaching support staff for teaching laboratories, for this paper all
85 will be referred to as TAs. Further, technical laboratory staff assist the educators in setting up the
86 laboratory experiments, calibrating and checking equipment and making solutions. Prior to the
87 pandemic, some educators had replaced traditional hands-on (on-campus) physiology
88 laboratories with non-traditional, virtual alternatives (13, 37). The terminology for non-
89 traditional laboratories in the research literature is confusing, with inconsistent use of terms such
90 as simulation and virtual, remote and distance laboratories (15). For this study virtual

91 laboratories are defined as students using virtual experiments, instruments or equipment via a
92 computer. A virtual laboratory can be completed individually or in teams, allowing students to
93 explore topics in a manner that has no immediate physical reality (7). Synchronous virtual
94 laboratories are completed by students at a scheduled time, whereas asynchronous virtual
95 laboratories are not scheduled and do not require real-time interactions. Examples of virtual
96 physiology laboratories include those developed by faculty/academics and freely shared online
97 (31) and commercial products (ADInstruments®, <https://www.adinstruments.com>; Pearson®
98 PhysioEx™, <https://www.pearson.com.au/9780136447658>). Past drivers for moving to these
99 virtual undergraduate laboratories were lower costs (especially staffing) and concerns with
100 animal use (27, 32). In many cases, rather than replacing traditional laboratories, virtual
101 physiology laboratories have been used to supplement traditional laboratories, often using a
102 blended model of teaching (8, 10, 31). For this study, when the virtual laboratories were
103 completed online, and outside of instructional laboratory space, they were considered to be
104 ‘remote’ laboratories. Remote laboratories also included hands-on laboratories that can be
105 completed by the students off-campus, for example via portable laboratory kits (15).

106

107 Since the initial pandemic-related university shutdowns in March, 2020, there have been further
108 shutdowns triggered by additional waves of the pandemic in both the northern and southern
109 hemispheres. While the development of effective vaccines against SARS-CoV-2 provides hope
110 that these shutdowns will end, faculty and university administrators are now asking what
111 teaching will look like post-COVID, especially for resource-intensive laboratory courses. Thus,
112 it is important to document the successes and challenges with the move to remote laboratories.
113 The aim of this study was to document the experiences of physiology educators in rapidly

114 transitioning their laboratories for remote teaching during the COVID-19 pandemic. Ten
115 physiology educators from Australia, Canada, the U.K. and the U.S.A. wrote reflective narratives
116 in order to answer the research question '*What were the changes to physiology laboratories in*
117 *response to the COVID-19 pandemic?*' Reflective writing methodology was used, as reflection
118 on experiences contributes to understanding and learning about practice (22). The study
119 outcomes will provide recommendations for physiology educators as to how they can
120 successfully develop and deliver remote laboratories, or use aspects of remote laboratories in
121 future on-campus laboratories.

122

123 **METHODS**

124 ***Participant Recruitment***

125 The ten respondents for this study are all physiology educators (academics/faculty) at
126 universities. They were voluntarily recruited in June 2020, via an email invitation from the chief
127 investigator to an international community of physiology educators involved with the Physiology
128 Majors Interest Group, the Australian Physiological Society and/or The Physiological Society.
129 As all of the respondents for this study were also the researchers for the study, ethical approval
130 was not required for the study.

131

132 ***Protocol***

133 The research is situated within a theoretical perspective of interpretivism with an exploratory
134 qualitative research design used to investigate the research question (9) ‘*What were the changes*
135 *to physiology laboratories in response to the COVID-19 pandemic?*’ Written reflective
136 narratives, essentially autobiographical in nature, were used as the basis to describe the personal
137 experiences and actions of respondents as they transitioned physiology laboratories from a
138 physical to a remote mode of delivery (in response to the COVID-19 pandemic). Respondents
139 were asked to write reflectively, sharing their feelings, personal experiences and concerns.
140 Written narratives have been shown to have considerable value in research (22). The narrative
141 essays were written independently and were framed around five guiding questions that were
142 initially developed by the researchers for this study (see below). In addition to a question probing
143 the respondents’ experiences of transitioning to remote laboratories, the other questions aimed to
144 understand the respondents pre-COVID attitudes and experiences of virtual laboratories, and to
145 determine if these were altered by the COVID-induced shift to remote laboratory delivery. It was
146 decided that the term ‘remote’ rather than ‘virtual’ laboratory would be used, as this
147 acknowledged that in addition to the use of virtual laboratories, some educators replicated the
148 hands-on laboratories, with students experimenting on themselves at home.

149

150 *Guiding questions for the written reflective narratives*

151 (1) What were your experiences of virtual laboratories pre-COVID?

152 (2) Pre-COVID, what was your attitude to replacing on-campus laboratories with virtual
153 alternatives?

154 (3) How did you convert the on-campus laboratories to remote laboratories?

155 *What challenges and opportunities did you encounter?*

156 *Do you have any informal feedback from students or teaching associates about the remote*
157 *laboratories?*

158 (4) Has this experience changed your attitudes to remote laboratories?

159 (5) In the future, assuming we can resume on-campus laboratories, will you be retaining remote
160 laboratories?

161

162 ***Analysis***

163 The narrative essays, from now on referred to as reflections, were written by the respondents in
164 July 2020, then de-identified for thematic analysis, with the names of the respondents,
165 institutions and subjects/topics/units/courses removed. Thematic analysis of the reflections
166 followed the six-phase process described by Braun and Clarke (4): (1) familiarization with the
167 data; (2) initial coding of the data; (3) searching for themes; (4) reviewing the themes; (5)
168 defining and naming themes; and (6) producing the report. The analysis was performed by all of
169 the researchers. In order to build a narrative knowledge, each respondent read all other
170 reflections (22). Narrative knowledge uses the particular experiences of one situation to create a
171 link from the personal nature of reflective writing to findings that are more widely applicable and
172 disseminated publicly. While reading the reflections, respondents identified common themes.
173 Each person, in a pair of respondents, independently analyzed one of the guiding questions

174 across all of the reflections, using an open-coding approach to highlight common and interesting
 175 aspects of the reflections (35). The codes and quotations to support these codes were put into an
 176 *Excel* spreadsheet. The analysis pairs met to discuss the data from their assigned question and to
 177 reach a consensus on the codes. Whilst the initial coding was used as a foundation for this
 178 process, pairs revisited the reflections, in particular to determine if aspects of the question had
 179 been answered elsewhere in the reflection.

180

181 **RESULTS**

182 All respondents in this study were full-time physiology educators (academics/faculty) at a
 183 university in either Australia, Canada, the U.K. or the U.S.A. See Table 1 for information about
 184 the respondents and their laboratory courses before the onset of the COVID-19 pandemic.

185

186 *Table 1. Information about the study respondents and their pre-COVID laboratories*

Years as physiology educator	Average: 17 (SD 5); Range: 8 - 25+
Degree programs	Bachelor (Science, Biological Science, Health/Medical Science).
Level(s) of students	1=11%; 2=33%; 3=33%, 4=23% (<i>Australia doesn't have 4-year programs</i>)
Cohort size	Average: 295 students; Range: 50 - 600
Learning outcomes	Mix of physiology concepts and research skills
Types of laboratory assessments	Multiple choice question quizzes (pre, post, in-class), laboratory reports, short answer questions, laboratory/practical test
Assess research skills?	Yes = 70%; No = 20%. Research skills assessed: experimental design, data

	collection and recording, statistical analysis, referencing, communication, critical and data analysis/interpretation, problem solving.
Teamwork	Yes (n=10). Average team size: 4 students (SD 1); Range: 2 - 6
Number of students assigned to each instructor (faculty/academic or TA)	Average: 15 students to 1 instructor (SD 5); Range: 8 - 24
Pre-laboratory online content	Yes (n=8; 6 with pre-lab online quizzes based on the lab content and/or protocols). No (n=2; one asked the students to review the relevant lectures and one asked the students to come to the lab with a protocol flow chart – neither were assessed)
Are the laboratories compulsory? Was attendance taken?	Yes (n= 8; attendance registered); No (n=2; attendance not registered)

187

188 **What were your experiences of virtual laboratories pre-COVID?**

189 Within the respondent group only one person had previously converted to predominantly virtual
190 laboratories, with limited hands-on activities. Four of the ten respondents ran only in-person
191 laboratories. One respondent hosted in-person laboratories with some use of a virtual laboratory
192 to either preface the actual laboratory or as an alternate format. As one respondent explained “*we*
193 *had been forced to adopt simulations (due to [lack of] animal availability)*”. For another
194 respondent, online pre-laboratory activities were being used to prepare students for in-person
195 laboratories. This “*helped with the smooth/trouble-free completion of the actual practical class*”.

196

197 **Pre-COVID, what was your attitude to replacing on-campus laboratories with virtual**
198 **alternatives?**

199 There was unanimous agreement between respondents that in-person, on-campus laboratories
 200 were worth offering despite financial and ethical challenges. This attitude was explicitly stated
 201 by seven of the ten respondents and could be inferred from comments made by the others. Key
 202 themes that emerged for this question were that respondents thought that remote laboratories
 203 would not be as engaging or authentic as on-campus laboratories, they would not support social
 204 engagement and active learning, and they would not achieve the learning outcomes for
 205 laboratories. In addition, it was noted that students and their parents' value and expect in-person
 206 laboratories. See Table 2 for the main themes related to virtual laboratories, with selected quotes
 207 from respondents that reinforce the themes.

208

209 ***Table 2. Respondent attitudes to replacing on-campus laboratories with virtual alternatives***

Theme	Selected quotes
Virtual laboratories would not be engaging or authentic	<p><i>“We had previously found it hard to get students to engage during such [virtual] sessions and some staff always found them predictable and boring.”</i></p> <p><i>“I felt for my students, clicking their way through relatively uninspiring (though scientifically thorough) virtual simulations of experiments.”</i></p> <p><i>“I felt students didn’t get to grips with understanding the techniques and the experiments themselves were very repetitive. The students performed the experiment, following the protocol with very little thought or understanding.”</i></p> <p><i>“. . . nor would they [students completing virtual laboratories] have to deal with something like troubleshooting when something goes wrong”;</i></p> <p><i>“most online simulations lacked the uncertainty that occurs with different experiments, and there was a lack of diversity for any human experiments, videos or data.”</i></p>

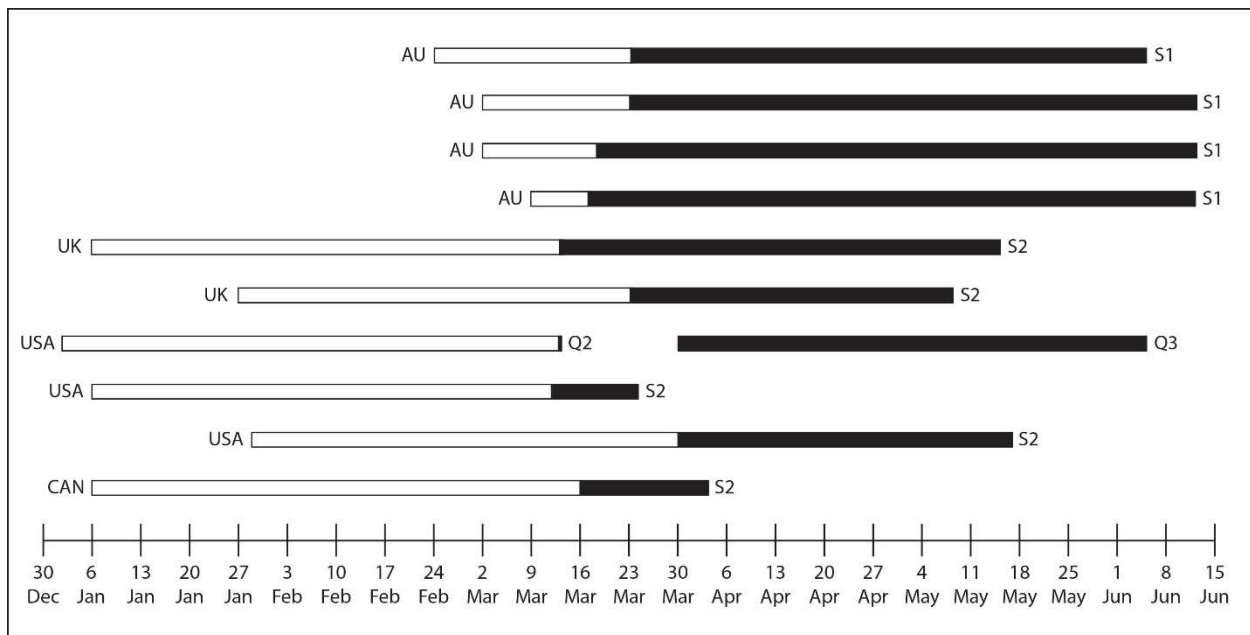
<p>On-campus laboratories support learning and build social connections better than virtual laboratories</p>	<p><i>“face to face practical classes . . . provided opportunities for students to interact with teaching assistants, academics and with each other and the general consensus that this social environment supported student learning and engagement.”</i></p> <p><i>“My teaching philosophy is based on . . . on active learning pedagogy and inspiring and supporting students to learn . . .”</i></p> <p><i>“it was a time [in-person laboratories] where you could really spend more time with students and find out what they were struggling with and whether the class had really understood what you had been talking about in class.</i></p>
<p>Virtual laboratories would not meet the learning outcomes</p>	<p><i>“We felt students would not have as adequate an opportunity to practice and hone these [research] skills using an online interface. We wanted students to appreciate the subject to subject variability that comes with authentic research.”</i></p>
<p>Belief that positive personal experiences of on-campus laboratories cannot be replicated online</p>	<p><i>“These experiments, in my memories, were a complex tapestry of olfactory, tactile, ethical and emotional reactions – will the next snip of the scissors sever the sciatic nerve?... These experiments had their roots in some of the earliest and most fundamental physiology experiments.”</i></p>
<p>Student, parent and educator expectations that on-campus laboratories will be provided</p>	<p><i>“students frequently commented about how much they enjoyed the practical laboratory classes and how they supported their understanding of physiology content.”</i></p> <p><i>“students and their parents often associate the quality of the courses with the number of hours the student spends in face to face teaching including practical classes.”</i></p>
<p>Challenges of getting colleagues to embrace virtual laboratories</p>	<p><i>“Trying to change the mindset of colleagues within the school, many [of] whom have been part of the original team designing practical courses of the past was a difficult challenge. They could not see how using virtual lab experiments, or even pre-or post-lab work, would train students to be competent in the research skills required to be proficient in their labs during the final year of study.”</i></p> <p><i>“I think a lot of my colleagues were actually quite scared about what would happen if a class failed if the technology didn’t work. . .”</i></p>
<p>Virtual laboratories can prepare students for on-campus laboratories</p>	<p><i>“A simulation/online practical might be good to provide preparatory experience before doing the actual lab work.”</i></p> <p><i>“Online or virtual labs seemed like a reasonable approach for specific lab protocols that weren’t feasible because of financial, facility and/or safety limitations. I felt that these were good supplements to a course that was otherwise taught in person with hands-on activities.”</i></p>

210

211

212 *How did you convert the on-campus laboratories to remote laboratories?*

213 The educational response to COVID-19 was abrupt and shocking. Half the respondents taught
 214 their first remote laboratory within 48-hours to one week of being notified. A few were given
 215 some reprieve when their institutions transitioned to a non-teaching week to allow staff time to
 216 prepare for the transition. Others had experience implementing remote teaching for a small group
 217 of international students before they were locked down locally. Since the respondents teach at
 218 institutions around the world with different academic years and teaching terms (e.g. semesters,
 219 quarters), the move to remote laboratories (mid to the end of March) occurred at different points
 220 in the delivery of their courses (see Figure 1). For one respondent the laboratory course had been
 221 completed in the previous semester, but for others the disruption came at the start of the semester
 222 (Australia), in the middle of the semester/term (U.S.A) or towards the end of the
 223 semester/quarter (U.S.A. and U.K.).



224

225 **Figure 1. Critical academic term (or semester) dates at the universities of the respondents.**
226 *White bars begin at the start date of each term. Black bars begin when each university switched*
227 *to remote delivery due to COVID-19; black bars terminate at the end of each instruction period*
228 *for the term (excluding final exams). Countries of respondents: Australia (AU); United Kingdom*
229 *(U.K.); United States (U.S.A.); Canada (CAN). S1, S2, Q2, Q3: Semester 1, Semester 2, Quarter*
230 *2, and Quarter 3, respectively.*

231

232 With such a short timeframe to pivot to remote teaching, it is notable that six out of ten
233 respondents converted all of their laboratories to remote delivery, with another three cancelling
234 only one or two labs that were considered unsuitable for remote delivery. In general, this
235 required modifications to laboratory content to ensure content and learning outcomes were “*still*
236 *feasible*” and “*made sense*”.

237 Many respondents (60%) used commercially available online physiology laboratory resources
238 for all or some of their remote laboratories (e.g. Lt™ by ADInstruments®;
239 (<https://www.adinstruments.com/lr>). Videos were also widely used to present preparatory
240 material, explain equipment usage and/or demonstrate experiments, thus preserving some content
241 delivery from the in-person laboratories. A majority of respondents also reported using sample
242 data, collected internally in preceding years or provided by a commercial partner, to allow
243 students to practice the skill of data interpretation (e.g. ECG, lung capacities).

244

245 Many respondents wrote about the contributions of experienced TAs, or demonstrators, and
246 laboratory technicians who helped re-design and develop remote laboratories. Laboratory
247 technicians “*rapidly retrained to provide expert support for teaching online*”, leading the
248 development of videos to accompany remote laboratories and updating or generating
249 experimental data. TAs also took on new roles for the first time, assisting with video
250 development and online marking, responding to student emails and discussion board posts, and
251 chatting with students online “*in an attempt to remove the sense of isolation*” felt by students.

252

253 Approximately half of the respondents identified a need for greater flexibility in laboratory
254 delivery to accommodate students who were travelling, in other time zones or seeking paid work
255 to support their families. Changes included making laboratories non-compulsory for all students
256 or for some students in some instances; allowing more class swapping; and only assessing “*4 out*
257 *of 5*” labs to give students a buffer to adjust to the new delivery mode. Increased flexibility also
258 included providing asynchronous lab options. Only three of the five respondents had entirely
259 synchronous remote laboratories with four offering entirely asynchronous labs and three
260 respondents describing combined synchronous/asynchronous offerings (e.g. synchronous
261 laboratories that were recorded for absent students).

262

263 **What challenges did you experience?**

264 Making the transition to remote laboratories was a challenge for all respondents, especially given
265 the brief transition time from on-campus to remote teaching. Specific challenges such as

266 workload and expertise constraints, disparities in online access and workspaces, issues with
267 academic integrity, and educator or student stress were directly related to the pandemic. Other
268 challenges such as changes in learning outcomes and reduced student-student and student-
269 educator engagement, are commonly encountered with remote learning and were similar to the
270 concerns about virtual laboratories that the respondents had pre-COVID. Specific challenges are
271 summarized below.

272

273

274 *Workload and expertise constraints*

275 The reformatting of the laboratories and assessments involved retraining both educators and TAs
276 and resulted in additional TA hours. Many assignments that had been team-based or group
277 projects became multiple individual projects. To make the grading workload manageable, some
278 respondents shortened or simplified assignments. Eight out of the ten respondents saw an
279 increase in the number of students to each instructor for remote laboratories (compared to past
280 on-campus laboratories). Reasons cited for this increase included the changing institutional
281 financial situation, some TAs being prevented from teaching due to personal health issues, or
282 overwhelmed lead lab instructors not having the capacity to appropriately supervise less
283 experienced TAs.

284

285 Students not only had to master course content, but also had to navigate the online environment.
286 Educators had to become the technical support expert who trained TAs and other less

287 technologically savvy educators. Consequently, respondents described making assessment
288 allowances due to changing workloads, the inability to effectively deliver the same quality and
289 quantity of content, and the reality of student inequities. Another respondent wrote of the
290 technical challenge of online assessments: *“We resorted to emailing students questions, who
291 wrote out answers, photographed them and sent them back. This was the easiest way to
292 overcome technology and connectivity issues.”*

293

294

295

296 ***Educator and student disparities for online access and a quiet workspace***

297 Disparities in internet access were common in terms of both the speed of internet connectivity
298 and in the time of access and were experienced by students and instructors alike. For
299 international students, internet access was further constrained by national firewalls. For many,
300 *“facing”* one’s students meant overcoming webcam problems on both sides of the video
301 exchange. One respondent reported *“A few students had to sit in the parking lot of a local library
302 to access the internet when their internet was down”*. External socio-economic ramifications of
303 the pandemic led to non-ideal study environments, and conflicting priorities both for family
304 internet access and for time-sharing between work and school in families that had lost income.
305 From another respondent *“I was also aware that some of our students did not have a private
306 working space at home, or may have been embarrassed by their living conditions, and so made a
307 point of not requiring students to use cameras in my classes”*. In some instances, alternate

308 assignments were required for these students. Further, university representatives had to vet user
309 agreements of online platforms to safeguard user and network security.

310

311 ***Educator and student stress***

312 The challenges outlined previously greatly increased both educator and student stress (as
313 perceived by the educators). Respondents reported that they felt panic or that things were out of
314 control. This anxiety was multifactorial, reflecting a concern about the quality of educational
315 materials developed in such a short timeframe, as well as more generalized anxiety around the
316 social impact of COVID-19 and the physical and/or mental wellbeing of colleagues and personal
317 connections. One respondent reported that “*out of my 7 TAs, 3 struggled [with]... overwhelming*
318 *anxiety*”. The reflections also included reports of shock, denial and anger – “*I could not believe*
319 *what was happening, it made no sense*”, “*initially I was pretty ticked off that this was*
320 *happening...almost in denial*”. Together, these reflections suggest some educators went through
321 a process akin to grief, perhaps for the teaching, or the normality, we had suddenly lost.

322

323 ***Loss of teamwork and educator-student or student-student interactions***

324 Several respondents were challenged by the loss of in-person, face-to-face interactions with their
325 students. They commented that it was difficult to communicate expectations and felt
326 disconnected from their students. One stated “*Even during Zoom office hours, many never turned*
327 *on their camera or microphone, choosing to communicate via chat box, so I only know them as a*
328 *name on a screen.*” In particular, the usual cues used to gauge learning were lost with the move

329 to remote laboratories, especially since many students had their cameras turned off. *“With no*
330 *way to look at students faces and gauge their understanding, or adjust my pace to their needs,”*
331 one respondent wrote, *“I felt insecure about my teaching for the first time in a long time . . .”*
332 and another reported *“the greatest challenge of ...delivering course content online was the loss of*
333 *ongoing student feedback that drives my teaching in face-to-face labs”*.

334

335 Student teamwork often defines the in-person laboratory experience. Respondents struggled to
336 recreate this for remote laboratories. The shift to remote laboratories was associated with a
337 reduction in teamwork for nearly half of the respondents. A range of reasons were given for the
338 reduction or removal of teamwork after the start of the pandemic, including social distancing
339 requirements and the lack of options for team logins and/or assignment submission with popular
340 commercially-available online physiology lab platforms. One respondent insightfully reflected
341 that *“the rapid nature of the transition meant that there was no time for a meaningful setup of*
342 *teams in an online . . . environment”*. Another stated that one of their core goals for remote
343 laboratories was *“to maintain the interactive nature of on-campus laboratories”* and four others
344 retained teamwork in their remote laboratories. Loss of teamwork led, together with diminished
345 teaching funds, to increased workload, as described by this respondent *“Practical marking was*
346 *an enormous task, approx. 2300 assessments, due to group assessments changing to individual*
347 *assessments. We did not have access to any further casual funds and needed to absorb the extra*
348 *workload...”*

349

350 ***Reduced student and TA engagement***

351 Respondents reported that their students seemed less engaged with the course material, with
352 fewer students prepared for the remote laboratories. Some students prioritized work over classes
353 due to family job losses, and there was more absenteeism. One respondent stated "*Many*
354 *undergraduates had their schedules upended by abruptly moving back home or taking an extra*
355 *delivery job to make ends meet*". The virtual laboratory delivery made it harder to keep the
356 attention of students, and students seemed to have difficulty visualizing or understanding content
357 despite supplemental videos. In addition, students procrastinated and completed the virtual
358 activities close to the due date rather than during the originally allocated laboratory session. One
359 respondent reported that TAs were less prepared for remote delivery, perhaps because they were
360 attempting to balance research, teaching, and marking or were preoccupied with closing their
361 supervisor's laboratory. This respondent elaborated "*they [the TAs] were expected to do the*
362 *simulations themselves so that they could answer student questions, but I can see from the*
363 *simulation logs that only 2 TAs consistently did the simulations*".

364

365 ***Changes in learning outcomes and assessment***

366 With the use of pre-recorded laboratory data, reduced contact time with students, and the
367 simplification or reduction in the number of student assignments, for some respondents the
368 learning outcomes had to be reconsidered and often modified in the transition to remote delivery.
369 The inability to replicate some on-campus laboratory exercises, and the difficulty of arranging
370 opportunities for students to design and carry out their own experiments diminished learning
371 outcomes. Despite the advances in online laboratory platforms, the perceived need to give
372 students "*good*" data to analyze had the consequence of taking away the "*Aha*" moment. It also

373 robbed the students of the appreciation of biological variability and failed to convey the value of
374 failure in the experimental endeavor. One respondent noted: *"One of the biggest losses in the*
375 *online lab was students not being able to design and carry out some of their own experiments."*

376

377 There was further difficulty in assessing student learning, both through written exams and
378 laboratory exercises. Exams, in many cases, were open book and online instead of closed book
379 (proctored/invigilated) and on campus. Educators grappled with how to conduct tests and exams
380 online and stated that they were concerned with academic integrity, including plagiarism and
381 cheating. One respondent reported, *"there was concern with an increase in the incidence of*
382 *student cheating, which appeared to students to be easier to carry out, despite the unbeknownst*
383 *ability of faculty to use technical tools to reveal such cheating"*. One respondent acknowledged
384 that since it was very difficult to prevent cheating on laboratory assessments and exams in an
385 online setting, that priority was now being placed on fostering student learning and engagement
386 rather than ensuring closed book assessments.

387

388 **What opportunities did you encounter?**

389 Aside from the challenges faced by educators and students due to the sudden lockdown
390 associated with the COVID-19 pandemic, many respondents found opportunities to grow and
391 change, explore new technologies, fast track projects already in the works and initiate
392 collaborations on a scale never seen before. No longer was there an "idea" or a "desire" to create
393 an online learning platform, COVID-19 mandated it. Highlights are described below.

394

395 ***Staff development and collaborations***

396 Many respondents found a unique opportunity to engage in their own professional development.

397 One stated: *"I probably went to more faculty meetings in one quarter than the previous year to*

398 *talk about the constantly evolving situation and share work [being done] in our remote classes. I*

399 *came away with a lot of ideas for what to do differently in Fall."* Seven out of ten respondents

400 described greater interdisciplinary collaborations and teamwork opportunities, both inside and

401 outside their own institutions. The rapid nature of the shutdown made it imperative to work

402 together. Technical staff became central learning partners assisting educators in developing

403 learning platforms, demonstration videos, and resources that would be of long-term value. This

404 also generated an openness amongst educators to form interdisciplinary teams to better meet the

405 learning goals of their students. As one respondent noted: *"[the development of online labs was*

406 *achieved through the] coordinated efforts of a team of unit and support staff, who contributed*

407 *more than they ever had to...[their] level of commitment, and their flexibility and ongoing*

408 *adjustments to accommodate the changing situation and continue to support academic staff,*

409 *were extraordinary"*. At many institutions, technical staff, but not educators, were considered as

410 essential workers and they remained on campus during lockdown. This meant they took

411 responsibility for developing recordings of human physiology experiments to support the remote

412 laboratories.

413

414 ***Exploring new technologies for remote laboratories***

415 Other opportunities included greater exploration and integration of technology and online
416 learning platforms with education companies. Some companies, such as ADInstruments®
417 (<https://www.adinstruments.com>), Biopac® (<https://www.biopac.com/>) and Pearson®
418 ([https://www.pearson.com/uk/educators/higher-education-educators/subjects/he-stem/he-](https://www.pearson.com/uk/educators/higher-education-educators/subjects/he-stem/he-anatomy-and-physiology.html)
419 [anatomy-and-physiology.html](https://www.pearson.com/uk/educators/higher-education-educators/subjects/he-stem/he-anatomy-and-physiology.html)), produced ready-made online integration tools, and other
420 companies and professional societies sponsored webinars to help educators make better use of
421 existing online tools. Three of the respondents were using Lt™ by ADInstruments®
422 (<https://www.adinstruments.com/lt>) before the pandemic and continued to do so as their primary
423 learning platform. They were able to substitute pre-recorded data of physiological parameters
424 provided by the company for virtual instruction. Two of the respondents used Pearson®
425 PhysioEx™ (Laboratory Simulations in Physiology,
426 <https://www.pearson.com.au/9780136447658>) before and during the pandemic. Another
427 technology program that was well regarded was Perusall® (<https://perusall.com/>), which allows
428 students to continue to work in teams to annotate and comment on journal articles. A respondent
429 stated (about Perusall®): *“The student comments are graded via artificial intelligence, so the*
430 *time requirement for teaching assistants was minimal.”*

431

432 ***Revisiting and redeveloping laboratory teaching curriculum and resources***

433 At least half of the respondents found themselves rethinking the overall curriculum and
434 laboratory structure, in addition to the types of laboratory assessments and topics traditionally
435 taught. Many redeveloped their curriculum to better match the course learning outcomes. One
436 respondent wrote, *“we are ironically grateful to have been forced to question our learning*

437 *outcomes and the processes we have been using to achieve them."* Another wrote *"the pandemic*
438 *situation has made us question whether the way we performed this class in person was giving the*
439 *students the best experience in gaining the practical skills they required"*. Similarly, from
440 another respondent, *"Running entirely online practicals has forced me to acknowledge that we*
441 *are not, and have not for a long time, been providing genuine practical training in my unit."*
442 Many respondents rewrote various laboratory activities and generated new materials, including
443 the recording of data sampling videos and laboratory protocols. Others employed asynchronous
444 pre-laboratory lessons whose completion prior to the commencement of the laboratory exercise
445 was mandated. This improved the clarity of laboratory activities and allowed for incorporation of
446 case study and healthcare simulations that fostered laboratory professional skills. The changes
447 gave educators and students time to discuss and interpret recordings with data that was cleaner to
448 analyze. The streamlined approach allowed for greater accessibility and flexibility for students,
449 while being potentially more cost effective for schools and departments.

450

451 **Feedback on the remote laboratory experience**

452 The respondents were asked to share their impressions of student engagement, as well as
453 anecdotes and informal feedback from students, staff, and peers. Formal feedback (i.e. from
454 student evaluations of teaching) was not provided due to institutional research ethics
455 considerations.

456 Seven of the respondents reported that although the circumstances were difficult, they thought
457 that educators, staff, and students had positive experiences. Students were satisfied and felt that
458 they had been able to engage with the course as much as possible under the circumstances.

459 Others stated, “*student engagement was still high, attendance was good for optional tutorials*”,
460 and “*students thought the new remote systems were easy to use and were impressed at how*
461 *quickly faculty put these together.*” One respondent quoted a student as saying “*Having a virtual*
462 *experiment to be able to observe the experimental setup gave really good context and helped me*
463 *understand what was happening.*” Almost half of the respondents reported that the remote
464 laboratories “*were well received by students and added elements to my class that I didn’t have*
465 *previously.*” Flexibility was mentioned several times as a positive aspect of remote delivery,
466 especially for students who had had a change in employment or were in different time zones. In
467 one reflection, there was clearly a desire to maintain that flexibility: “*My hope from all this is*
468 *that it might make our degrees more accessible and flexible for those students and staff who have*
469 *long needed this but haven’t been able to have it.*”

470 In the shift to remote laboratories, interactions between people changed in ways that were both
471 positive and negative. A positive aspect was that students showed greater appreciation for
472 educators’ efforts and even enjoyed many of the demonstration videos and simulations that
473 educators provided for students to engage with the data. The unorthodox feel of some home-
474 made videos may have had increased appeal to students: “*Really liked the personal videos of ___*
475 *in her kitchen. Really made it entertaining.*” Some respondents extended their interactions with
476 students beyond the course material. One respondent described creating a weekly “check-in” to
477 monitor students’ well-being. Students “*felt like someone was looking out for them and cared*
478 *about them as human beings*” and students with social anxieties reported increased engagement
479 with the material due to less social stress. Nevertheless, some students missed the in-person
480 laboratories as they placed “*a high value on being able to physically touch and manipulate.*”

481

482 **Has this experience changed your attitudes to remote laboratories?**

483 In general, after the experience of transitioning to remote laboratories, many respondents still
484 believed that the remote version was less holistic in its approach than the on-campus, in-person
485 laboratory. Despite this, there was less resistance to and a new appreciation for remote teaching
486 and indeed virtual laboratories, with a realization by at least one respondent that "*...we have not*
487 *actually been providing a true lab experience for many years and will continue to offer an online*
488 *option in future years*". Another respondent found the new pre-laboratory activities beneficial
489 "*the asynchronous pre-lab learning environment that we were able to create resulted in students*
490 *actually being much better prepared for their laboratory exercise than occurred with our normal*
491 *modality.*" For some, the remote transition strengthened previous beliefs that virtual laboratories
492 are a good supplement, but not a replacement, with students not having an appreciation of how
493 challenging it can be to set-up and troubleshoot experiments. The lack of opportunities for
494 teamwork, data collection, hands-on skill development, and poor understanding of the nature of
495 biological variability were also concerns.

496

497 **In the future, assuming we can resume on-campus laboratories, will you be retaining**
498 **remote laboratories?**

499 Respondents overwhelmingly supported retaining some element of remote delivery of laboratory
500 teaching in the future. The remote laboratories provide flexibility to suit student preferences and
501 circumstances (e.g. international students who could not immediately return to campus). One
502 respondent wrote: "*Running entirely online practical classes has forced me to acknowledge that*
503 *we are not, and have not for a long time, been providing genuine practical training. As such, the*

504 *experience has confirmed an obligation to provide more flexibility for students in the future”.*
505 While another reported to be now *“better placed to design a more meaningful and contextualized*
506 *practical curriculum”.*

507

508 The concept of using a blended model where students are engaged more with pre- and post-
509 learning outside of the laboratory (virtual) in addition to in-person laboratories appealed to some:
510 *“it has strengthened my previous beliefs that online modules are a good supplement, but not a*
511 *replacement”.* A concern raised by one respondent was the cost of the commercial online
512 laboratories, though the other respondents reported that their faculties/departments had covered
513 the cost and planned to do so in the future. In some cases, the cost of the online laboratories
514 is/would be borne by students.

515

516 **DISCUSSION**

517 This study illustrates a collective determination by physiology educators to retain physiology
518 laboratories in extremely challenging circumstances, highlighting the importance that they place
519 on laboratories as a learning experience. Even without a pandemic, the transition to online
520 teaching is challenging, therefore it was not surprising that this involuntary and abrupt transition
521 to ‘emergency remote learning’, or remote laboratory delivery, often with little institutional
522 support and the isolation of working from home, was associated with poor educator (and student)
523 wellbeing. While a strong theme in the reflections, the high levels of personal stress experienced
524 by all involved will not be discussed here, to allow for discussion of results that have more

525 explicit implications for the future of physiology laboratories. The pandemic-induced shift to
526 remote laboratories was also associated with challenges such as excessive workloads, unfamiliar
527 technologies and loss of interactions between educators and students. Conversely, this crisis
528 triggered opportunities for staff development, international communities of practice and the
529 rediscovery of why and how we teach physiology laboratories and what we hope they
530 accomplish. In the future, even with on-campus laboratories, most of the respondents planned on
531 retaining some successful aspects of the remote laboratories, particularly with a blended model
532 of remote and on-campus laboratories. Thus, highlighting that there were successful aspects for
533 the rapidly implemented remote laboratories. This discussion focuses on the key challenges and
534 opportunities associated with remote laboratories and includes recommendations and practical
535 strategies to improve the delivery of the online aspects of blended physiology laboratory courses
536 in the future (see Table 3).

537

538 *Educator-student and student-student interactions for remote laboratories*

539 A majority of the respondents' attitudes pre-COVID reflected beliefs that virtual laboratories
540 would not support social interactions, nor active learning, when compared to on-campus
541 laboratories. It was thus not surprising that these beliefs also emerged as challenges for
542 respondents when they transitioned to remote laboratories. It has been shown that limited social
543 interactions during online courses diminish student engagement and contribute to higher attrition
544 rates (38). Many respondents mentioned a drop off in student engagement with remote
545 laboratories, as evidenced by students' unwillingness to contribute to online forums, with their
546 cameras off and little appetite to communicate outside of the chat function. In most physiology

547 courses, on-campus laboratories are the primary opportunity for social interactions, suggesting
548 that physiology educators should be proactive about adopting remote laboratory replacements
549 that facilitate student-student (and student-educator) interactions.

550

551 Four strategies that can be used to facilitate online interactions for remote laboratories include 1)
552 synchronous, video-based delivery, 2) educator presence, 3) small teams and 4) collaborative
553 assessments. Synchronous online communication, using a video tool to add human perspective
554 (e.g. Zoom™; <https://zoom.us/>), increases online social interactions by providing essential visual
555 social cues (21). Indeed, most of the respondents maintained a high level of educator presence
556 within synchronous laboratories facilitated by online video-based platforms. However, most
557 were unable to keep lower educator-student ratios or small teams, factors that reduce the
558 transactional distance between the students and educators, increasing the possibility of
559 interactions online (11, 21). Team-based collaborative activities and assessments, such as applied
560 or problem-based projects, encourage student online interactions, especially when they are
561 completed during a synchronous laboratory (12, 17). This could be achieved with remote
562 laboratory assessments that involve data analysis and interpretations, or with team-members all
563 accessing the remote laboratory data acquisition process at the same time (28).

564

565 ***Teamwork for remote laboratories***

566 Student teamwork was a unifying feature of pre-COVID physiology laboratories for respondents.
567 Skills around teamwork (working collaboratively and cooperatively with others, appreciating and

568 valuing different views, communicating effectively) also feature among the transferable
569 professional skills identified as important for physiology graduates (16). Despite this, nearly half
570 of the respondents reported a removal or reduction of teamwork immediately following the
571 transition to remote laboratories. Many factors contributing to this reduction were mostly
572 transient and specific to this COVID-19 period, such as unfamiliar technologies, high stress
573 levels, student and faculty health status, geographical location, and even shifting work and
574 family obligations. In this context, it may not have been feasible, nor equitable, to require
575 students to engage in teamwork. However, some factors may persist for years because of the
576 broader global situation (e.g. ongoing financial consequences of COVID-19 for universities,
577 travel restrictions and public health considerations, increased student demands for flexibility).
578 Some respondents in this study, suggested that some aspects of their remote laboratories will be
579 permanently retained. Thus, physiology educators will need to consider if and how learning
580 outcomes around teamwork can be attained and assessed for remote laboratories, in spite of
581 factors that make online teamwork challenging.

582

583 Successfully developing teamwork skills in online contexts may start with the acknowledgement
584 that online and in-person teamwork require overlapping, but not identical, skill sets (34). This in
585 turn requires a reconsideration of the parameters for, and scaffolding of, teamwork skills
586 development in remote laboratories. Common requirements for online and in-person teams
587 include the need for effective team leaders, equal distribution of workload between team
588 members, shared ownership of the task to integrate the individual members contributions and a
589 sense of “knowing” each other (38). However, online teams face particular challenges in
590 maintaining communication (e.g. navigating the absence of nonverbal/facial cues, disparate time

591 zones and cultural expectations) and developing trust within the team (1, 18, 24). In order to
592 support these processes for virtual laboratory teams, it can help if teams, when they initially
593 meet, agree upon a mode of communication, clarify the roles for the team members, are provided
594 with training of model collaborative skills as well as facilitation and involvement of the educator
595 throughout the teamwork process (29, 33).

596

597 Careful planning of online laboratory teams could mitigate some of the challenges for online
598 teamwork. For example, when students are navigating online teams for the first time, it may be
599 preferable to assign students to teams from the same time zone and geographical location.
600 Software solutions that facilitate assigning students to teams based on their preferences and/or
601 academic ability may also prove helpful in this space (6). A relatively straightforward strategy to
602 accelerate establishment of trust within online teams is to schedule an initial in-person meeting
603 before online teamwork starts. Ideally, this would incorporate an educator-guided discussion of
604 online teams, particularly culturally diverse online teams, addressing potential challenges and
605 strategies to address these challenges (2). Many of the respondents intend to maintain a mix of
606 on-campus and remote laboratories. Ensuring that laboratory courses start with an on-campus
607 laboratory, where possible, is a simple strategy to accelerate the development of trust in blended
608 on-campus and remote physiology laboratory teams (18). Similarly, requiring students to work
609 with the same online team over a sustained period (e.g. the whole teaching period) provides time
610 for trust to grow in online teams (38).

611

612 *Modified learning outcomes for remote laboratories*

613 Respondents said that pre-COVID, they thought that virtual laboratories did not meet the same
614 learning outcomes as on-campus laboratories, particularly research skills development. Similarly,
615 a key challenge for the respondents with the transition to remote laboratories was modification or
616 loss of laboratory learning outcomes, especially research skills and teamwork. Whilst there is
617 evidence that virtual science laboratories are at least as effective for content knowledge as on-
618 campus laboratories, there is negligible evidence that they support research skills development
619 (5, 15, 27). Furthermore, they usually do not expose students to variability in scientific data, they
620 lack the collaborative and experiential learning that students experience during a physical
621 laboratory and they can lead to diminished student attention and knowledge retention when
622 compared to in-person laboratories (27). Some of these aspects were apparent for the remote
623 laboratories. For example, some respondents noted that students expected to be provided with
624 'perfect' experimental results. In addition, informal student feedback and performance on
625 laboratory assessments suggested that even when provided with videos of the experimental
626 processes, some students still did not seem to understand the experimental data they had been
627 asked to analyze.

628

629 An inability to cover the laboratory learning outcomes for remote delivery opens up a
630 conversation about what learning outcomes are required for a physiology program. For most
631 undergraduates undertaking a physiology major in science or biomedicine there are no
632 accreditation requirements for the attainment of specific physiology concepts or
633 professional/research/laboratory skills. It is hoped that newly developed physiology professional
634 skills, including laboratory proficiency, will be used to inform physiology laboratory curricula in
635 these degree-programs (16). In contrast, undergraduate Exercise/Kinesiology programs are

636 accredited. For example, Exercise and Sport Science Australia has Exercise Science Standards
637 that include “Interpret, explain and analyze physiological data obtained during acute exercise.”
638 (14). Whilst specific laboratory and research skills-based learning outcomes may not be
639 compulsory for undergraduate physiology studies, there is no doubt that the hands-on
640 experiences of human physiology experiments (i.e. students experimenting on themselves)
641 contributes to their understanding of physiology concepts and the scientific process (19) and, as
642 noted by a couple of the respondents, can trigger a passion for the discipline.

643

644 An additional consideration is whether or not post-bachelor programs (especially medical
645 schools) will accept virtual laboratory courses. In the United States, each medical school sets its
646 own standards for pre-requisite coursework. Most, but not all, require one year of laboratory
647 experience (either as a course or in a research lab), including physiology. Some explicitly state
648 that online courses are not acceptable, some are making an exception for COVID-19, and others
649 do not have a stated policy.

650

651 *Online Communities of Practice*

652 A positive outcome of the rapid transition to remote laboratories was that it prompted active
653 local (within their university) and global online collaborations (such as this study). This included
654 online engagement with physiology communities, such as the American Physiological Society,
655 The Physiological Society and The Human Anatomy and Physiology Society, which provided a
656 steady stream of online education webinars, workshops and forums since the start of the

657 pandemic. Locally, online teams formed with the technical laboratory staff, colleagues and TAs
 658 who worked together under time-pressure to rapidly learn new skills to develop the remote
 659 laboratories. Many respondents also reached out to international colleagues, particularly to share
 660 resources for remote laboratories. Interestingly, communities of practice research stresses
 661 learning through social interactions and collaboration (25), critical aspects of teamwork that
 662 respondents reported as being deficient with the remote laboratories. It is possible that
 663 respondents' experiences of these online communities of practice will help them to understand
 664 and support student social interactions and teamwork for future remote laboratories.

665

666 *Table 3. Recommendations for the development of remote physiology laboratories. Key*
 667 *considerations to take forward when developing future remote laboratories, developed from the*
 668 *main themes that emerged from the reflective narratives.*

<p>Planning</p>	<p>Rather than re-purpose existing on-campus laboratories, prepare and plan for remote delivery (i.e. assuming it is not an acute transition).</p> <p>Reconsider the learning outcomes to reflect remote delivery and the physiology concepts and research skills that can be achieved.</p> <p>Consider the use of hands-on activities that the students can perform at home on themselves (26).</p>
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<p>Delivery</p>	<p>Present remote laboratories in a consistent format, using a single platform.</p> <p>Film comprehensive videos that include the process of data acquisition for the laboratory.</p> <p>Reduce the content and timing for each remote laboratory (i.e. less content and time than an on-campus laboratory) – everything takes longer online, plus it is harder for students to maintain focus online.</p> <p>Encourage interaction and communication by providing and defining clear routes for two-way communication between educators and students (i.e. monitoring discussion boards, interactive feedback on the learning management system, weekly emails/forum posts/videos, online office hours, educator presence in synchronous remote laboratories).</p> <p>Use tools that facilitate collaborations such as polling, digital whiteboards and breakout rooms.</p> <p>Keep the educator-student ratio for online interactions as low as possible (11).</p> <p>Aim for at least some synchronous remote laboratories (as this will enhance instructor-student interactions) and monitor student attendance at these (12, 17).</p> <p>Use a blended model, with asynchronous online pre-laboratory content, followed by a synchronous remote laboratory.</p> <p>Use smartphone applications to allow students to recording physiological parameters from home (26).</p> <p>To facilitate teamwork, students could analyze physiological data from home, by remotely controlling the educator’s computer (3).</p>
<p>Assessment</p>	<p>Assess pre-laboratory activities to increase understanding and preparation for remote laboratories (and to ensure that students complete them).</p> <p>Reduce the number of assessed elements for each remote laboratory (things take much longer online).</p> <p>Embed team-based assessments into synchronous remote laboratories to increase student engagement and facilitate teamwork (17).</p> <p>Assign students to teams, taking into consideration academic abilities and whether the students are local or international. Teams should meet up consistently, have team-based assessments and have a dedicated teaching associate (33).</p> <p>Consider peer review for team-based assessments (this enhances student engagement and team building).</p>

Training	<p>Train teaching associates for effective online teamwork and incorporate some of this training into the first student team-based session (which will preferably be on-campus)</p> <p>Develop online modules to support and train staff to create online materials and use online platforms.</p>
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669

670 **Limitations and future directions:**

671 This study only captures the reflections of ten Physiology educators from ten different
672 universities. Thus, each reflection is the opinion of one educator from one institution. The
673 reflections are a ‘snapshot’ of educator opinions and perspectives at a point in time (July, 2020),
674 during which the educators were under considerable workload stress and experiencing a period
675 of global crisis. As well, not all geographic continents were covered in this study, with no
676 universities from Asia, Africa or mainland Europe. For this study, the geographical location also
677 altered the impact of the pandemic on physiology laboratories, as the start of the pandemic
678 coincided with the beginning of the 2020 academic year in Australia, whereas in the northern
679 hemisphere respondents were nearing the end of the academic year.

680 As the pandemic continues into additional waves, the intention is to have a follow-up study (with
681 the same respondents), preferably post-pandemic, as this will provide better insight into the
682 changing attitudes to remote physiology laboratories.

683

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Table 1. Information about the study respondents and their pre-COVID laboratories

Years as physiology educator	Average: 17 (SD 5); Range: 8 - 25+
Degree programs	Bachelor (Science, Biological Science, Health/Medical Science).
Level(s) of students	1=11%; 2=33%; 3=33%, 4=23% (<i>Australia doesn't have 4-year programs</i>)
Cohort size	Average: 295 students; Range: 50 - 600
Learning outcomes	Mix of physiology concepts and research skills
Types of laboratory assessments	Multiple choice question quizzes (pre, post, in-class), laboratory reports, short answer questions, laboratory/practical test
Assess research skills?	Yes = 70%; No = 20%. Research skills assessed: experimental design, data collection and recording, statistical analysis, referencing, communication, critical and data analysis/interpretation, problem solving.
Teamwork	Yes (n=10). Average team size: 4 students (SD 1); Range: 2 - 6
Number of students assigned to each instructor (faculty/academic or TA)	Average: 15 students to 1 instructor (SD 5); Range: 8 - 24
Pre-laboratory online content	Yes (n=8; 6 with pre-lab online quizzes based on the lab content and/or protocols). No (n=2; one asked the students to review the relevant lectures and one asked the students to come to the lab with a protocol flow chart – neither were assessed)
Are the laboratories compulsory? Was attendance taken?	Yes (n= 8; attendance registered); No (n=2; attendance not registered)

Table 2. Respondent attitudes to replacing on-campus laboratories with virtual alternatives

Theme	Selected quotes
Virtual laboratories would not be engaging or authentic	<p><i>“We had previously found it hard to get students to engage during such [virtual] sessions and some staff always found them predictable and boring.”</i></p> <p><i>“I felt for my students, clicking their way through relatively uninspiring (though scientifically thorough) virtual simulations of experiments.”</i></p> <p><i>“I felt students didn’t get to grips with understanding the techniques and the experiments themselves were very repetitive. The students performed the experiment, following the protocol with very little thought or understanding.”</i></p> <p><i>“. . . nor would they [students completing virtual laboratories] have to deal with something like troubleshooting when something goes wrong”;</i></p> <p><i>“most online simulations lacked the uncertainty that occurs with different experiments, and there was a lack of diversity for any human experiments, videos or data.”</i></p>
On-campus laboratories support learning and build social connections better than virtual laboratories	<p><i>“face to face practical classes . . . provided opportunities for students to interact with teaching assistants, academics and with each other and the general consensus that this social environment supported student learning and engagement.”</i></p> <p><i>“My teaching philosophy is based on . . . on active learning pedagogy and inspiring and supporting students to learn . . .”</i></p> <p><i>“it was a time [in-person laboratories] where you could really spend more time with students and find out what they were struggling with and whether the class had really understood what you had been talking about in class.</i></p>
Virtual laboratories would not meet the learning outcomes	<p><i>“We felt students would not have as adequate an opportunity to practice and hone these [research] skills using an online interface. We wanted students to appreciate the subject to subject variability that comes with authentic research.”</i></p>
Belief that positive personal experiences of on-campus laboratories cannot be replicated online	<p><i>“These experiments, in my memories, were a complex tapestry of olfactory, tactile, ethical and emotional reactions – will the next snip of the scissors sever the sciatic nerve?... These experiments had their roots in some of the earliest and most fundamental physiology experiments.”</i></p>
Student, parent and educator expectations that on-campus laboratories will be provided	<p><i>“students frequently commented about how much they enjoyed the practical laboratory classes and how they supported their understanding of physiology content.”</i></p> <p><i>“students and their parents often associate the quality of the courses with the number of hours the student spends in face to face teaching including practical classes.”</i></p>
Challenges of getting colleagues to embrace virtual laboratories	<p><i>“Trying to change the mindset of colleagues within the school, many [of] whom have been part of the original team designing practical courses of the past was a difficult challenge. They could not see how using virtual lab experiments, or even pre-or post-lab work, would train students to be competent in the research skills required to be proficient in their labs during the final year of study.”</i></p> <p><i>“I think a lot of my colleagues were actually quite scared about what would happen if a class failed if the technology didn’t work. . .”</i></p>

Virtual laboratories
can prepare students
for on-campus
laboratories

“A simulation/online practical might be good to provide preparatory experience before doing the actual lab work.”

“Online or virtual labs seemed like a reasonable approach for specific lab protocols that weren’t feasible because of financial, facility and/or safety limitations. I felt that these were good supplements to a course that was otherwise taught in person with hands-on activities.”

Table 3. Recommendations for the development of remote physiology laboratories. Key considerations to take forward when developing future remote laboratories, developed from the main themes that emerged from the reflective narratives.

<p>Planning</p>	<p>Rather than re-purpose existing on-campus laboratories, prepare and plan for remote delivery (i.e. assuming it is not an acute transition).</p> <p>Reconsider the learning outcomes to reflect remote delivery and the physiology concepts and research skills that can be achieved.</p> <p>Consider the use of hands-on activities that the students can perform at home on themselves (26).</p>
<p>Delivery</p>	<p>Present remote laboratories in a consistent format, using a single platform.</p> <p>Film comprehensive videos that include the process of data acquisition for the laboratory.</p> <p>Reduce the content and timing for each remote laboratory (i.e. less content and time than an on-campus laboratory) – everything takes longer online, plus it is harder for students to maintain focus online.</p> <p>Encourage interaction and communication by providing and defining clear routes for two-way communication between educators and students (i.e. monitoring discussion boards, interactive feedback on the learning management system, weekly emails/forum posts/videos, online office hours, educator presence in synchronous remote laboratories).</p> <p>Use tools that facilitate collaborations such as polling, digital whiteboards and breakout rooms.</p> <p>Keep the educator-student ratio for online interactions as low as possible (11).</p> <p>Aim for at least some synchronous remote laboratories (as this will enhance instructor-student interactions) and monitor student attendance at these (12, 17).</p> <p>Use a blended model, with asynchronous online pre-laboratory content, followed by a synchronous remote laboratory.</p> <p>Use smartphone applications to allow students to recording physiological parameters from home (26).</p> <p>To facilitate teamwork, students could analyze physiological data from home, by remotely controlling the educator’s computer (3).</p>

<p>Assessment</p>	<p>Assess pre-laboratory activities to increase understanding and preparation for remote laboratories (and to ensure that students complete them).</p> <p>Reduce the number of assessed elements for each remote laboratory (things take much longer online).</p> <p>Embed team-based assessments into synchronous remote laboratories to increase student engagement and facilitate teamwork (17).</p> <p>Assign students to teams, taking into consideration academic abilities and whether the students are local or international. Teams should meet up consistently, have team-based assessments and have a dedicated teaching associate (33).</p> <p>Consider peer review for team-based assessments (this enhances student engagement and team building).</p>
<p>Training</p>	<p>Train teaching associates for effective online teamwork and incorporate some of this training into the first student team-based session (which will preferably be on-campus)</p> <p>Develop online modules to support and train staff to create online materials and use online platforms.</p>

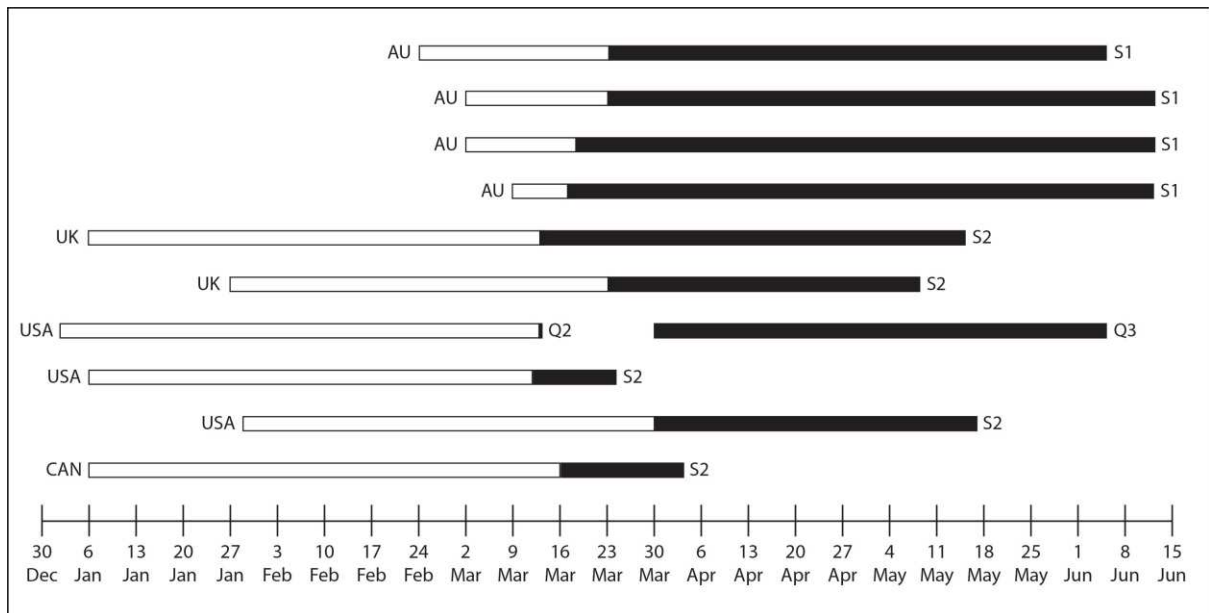


Figure 1. Critical academic term (or semester) dates at the universities of the respondents.

White bars begin at the start date of each term. Black bars begin when each university switched to remote delivery due to COVID-19; black bars terminate at the end of each instruction period for the term (excluding final exams). Countries of respondents: Australia (AU); United Kingdom (U.K.); United States (U.S.A.); Canada (CAN). S1, S2, Q2, Q3: Semester 1, Semester 2, Quarter 2, and Quarter 3, respectively.