Sustainable STEM practical work in education

by Timothy D. Drysdale | Institute for Digital Communications, School of Engineering, University of Edinburgh, Kings Buildings, Edinburgh, EH9 3FG, UK

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Sustainability considerations may provide a key to unlocking a long-standing issue in Science Technology Engineering and Mathematics (STEM) education. In the UK, there is a nationally-acknowledged "*skills crisis*" in STEM subjects in the United Kingdom, that has been building for approximately two decades. The symptoms are demand exceeding supply of graduates, and concerns over whether graduates are "work ready" [1]. The underlying reasons are complex, and not well understood. However, a contributory factor may be related to increasing pressure on in-person teaching laboratories. Significant capital investment is required to build more in-person laboratory facilities, so few have undertaken this. As a result, a typical higher education in-person laboratory sessions fall within a tightly-constrained timetable, lasting just long enough for most students to complete a streamlined set of steps from a lab-sheet, leading to a proscribed set of results. This does not fully reflect the world of work where open-ended development processes take place over extended periods. In other professions, alumni valued activities that more closely resembled their work environment as having prepared them better for their professional activities [2], so if similar principles apply in STEM subjects, then open-ended exploratory laboratories would represent better preparation. The level of investment required to support the required in in-person expansion of laboratory facilities is not widely affordable, nor would they be built in a timely manner [3]. Even were such facilities available, another sustainability issue arises. A greater or lesser proportion of experiments address a specific teaching point so are only used for a few weeks at a time, then put away again, unused for another year. After a number of years, perhaps five to ten, changes in the staff, their interests, and/or the curriculum may render the experiment un-needed despite it potentially having a significant amount of remaining service life. Even if other in-person users were available, e.g. from the arts and humanities, finding timetable time for them to visit the science campuses would be next to impossible because the experiments would be back in storage, and it would require transporting either the equipment or the staff and students. Considering these challenges highlights several attractive aspects of remote laboratories. Remote laboratories are self-contained experiments that are internet-connected, and accessible from any time-zone. This supports the virtual mobility of staff, students and equipment between institutions. Our expectation is that carbon footprint of streaming video and data is offset by the reduction in human travel, increased extraction of service life from raw resources, although detailed calculations remain to be undertaken. Our

implementation, used for three academic years so far, is based on an our open-source cloud infrastructure [4], and custom enclosure designs that permit them to be hosted in public spaces such as building foyers. This increases the practical and aesthetic value of the foyer space, without taking away any other research or teaching space. Without being limited by the in-person laboratory timetable, experiments can be conducted over a longer time frame, allowing exploratory work that better represents graduates' future professional practice.

[1] L. Armitage, M. Courner, J Di Simone, A Jones, S. Neave, "Engineering UK 2020 Educational pathways into engineering," Technical Report, EngineeringUK, https://www.engineeringuk.com/media/232298/engineering-uk-report-2020.pdf Last accessed 20 April 2023

[2] Leigh N. Wood, Jim Psaros, Erica French & Jennifer W.M. Lai (2015) Learning experiences for the transition to professional work, Cogent Business & Management, 2:1, DOI: 10.1080/23311975.2015.1042099

[3] T. D. Drysdale, S. Kelley, A.-M. Scott, V. Dishon, A. Weightman, R. J. Lewis & S. Watts (2020) "Opinion piece: non-traditional practical work for traditional campuses," Higher Education Pedagogies, 5:1, 210-222, 2020, DOI: 10.1080/23752696.2020.1816845

[4] Our source code is hosted at https://github.com/practable