Post—humanistic *'practices of community'* for non-traditional laboratory work

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ABSTRACT

Many traditional campuses face pressure on physical laboratory estate, making it difficult or impossible to simultaneously satisfy an enhanced level of active learning for an increasing number of students. Non-traditional practical work (NTPW) approaches such as virtual or remote labs can be delivered digitally, reducing estates pressure. There is emerging evidence that NTPW activities, especially when mixed with traditional laboratories, produce as-good or better educational outcomes than traditional laboratories alone. This hints at the idea that technology offers not just a replacement for existing practices, but the opportunity for enhancement, including directing and evaluating students through collaborations between teachers and non-human remote laboratory entities. Inspiration and insight can be drawn from critical post-humanism, which explores what happens when non-human actors exert influence in education. We look to understand the effect of widespread introduction of NTPW on students' practices during study and also in their subsequent professional practices. We use the field of Science and Technology Studies, to find a description of how students will come together in the socio-technological environment created by non-traditional practical work. Like the world in which our graduates are going to enter,

sociotech environments can be difficult to predict, which challenges the idea that best practice is a 'thing' that should be solidified, static, or final. It instead emphasises that practices (plural) are multiple, non-finalised performances that evolve over time. This must be reflected in the implementation, evaluation and support given to both staff and students.

1 INTRODUCTION

Engineering education needs to turn out better graduates to meet societal and industry needs, while demand levels simultaneously require us to graduate large cohorts. The MIT report on the global state-of-the-art in engineering education highlights this challenge:

"How do we deal with this expansion [of student numbers]? How do we still engage students early on with the world of engineering? How do we show them the messiness of engineering, the political and social aspects? ... How do we do this beyond the capstone project? This type of education, the type of education we want to have, is expensive. So how do you do this for all students, large cohorts of students, without compromising on everything?" [1].

Engineering education can only address these issues at the scale required by adopting non-traditional practical work (NTPW). NTPW is a group term to describe online digital alternatives such as simulated, virtual and remote laboratories. We also need to complement our existing understanding of engineering education with insight about relationships between students and NPTW activities, with a focus on improving student capabilities in real-world professional practice.

In Section 2, we highlight problems associated with traditional practical work, then explain NTPW and its benefits, including where NTPW activities could potentially take on some of the role of the human teacher and address some of the challenges of scale. In Section 3, we discuss the contributions that NTPW can make to navigating the curriculum, and enhancing graduate attributes that are relevant to their future careers in a rapidly evolving professional environment. In Section 4 we give an update on our progress toward understanding how NTPW should be implemented and evaluated across multiple institutions, and how we should support *practices of community* created by teachers, technical staff, and student co-creators.

2 PRACTICAL WORK IN THE AGE OF ACTIVE LEARNING

2.1 Traditional practical work

Traditional university campuses were often conceived and built at a time when fewer students were enrolled, and when there was less emphasis on practical work. Now, there is an increased desire for active learning, i.e. practical work that goes beyond simply following step-by-step lab sheets. Engineering's hierarchical knowledge structure means that active learning approaches from other fields are typically adapted into more managed forms, for example problem-based learning (PBL) becomes design-based learning (DBL) or project-based learning (PjBL), whose educational

appropriateness is broadly accepted [2]. These approaches are expensive and staff-intensive so they are typically limited to small cohorts, or are driven by individuals who manage to 'make do' despite being under-resourced [3]. Therefore, it is not possible to conceive of these methods being broadly adopted at scale. Even just modernising traditional laboratories on largely conventional courses is prohibitively expensive and therefore out of reach for many Universities.

Leaving aside cost, long lead times and working lives mean building-based solutions cannot be rapidly implemented or changed in response to developments. Within a physical building, activity timetabling is also problematic. Timetabling is one of the main barriers to students being able to freely select optional courses within a single programme and year of study, let alone facilitating students in different years, or on different programmes, to come together on projects involving peer-instruction or interdisciplinary working.

Physical laboratories also lag behind other elements of higher education provision in terms of their support for diversity and inclusion. If we want more diversity in the engineering profession, then we need to support not just larger cohorts, but also cohorts with more diverse needs. Physical laboratories arguably are one of the last high-stakes activities on campus. Sessions cannot typically be rescheduled or repeated if missed for reasons such as caring commitments. While lectures can be recorded, this is not a suitable solution for labs. Supporting diversity also means supporting a diversity of student engagement modes including private experimentation and thinking time [4]. So how then to create an alternative format to support diversity, accessibility and inclusivity? We argue that NTPW activities are an effective, resource sensitive, and pedagogically sound solution that can address these issues.

2.2 Non-Traditional Practical Work

At one level, NTPW is attractive because of its reduced delivery costs. For example, simulated and virtual experiments can be entirely delivered from a server, at any scale, at any time, to any location. Remote experiments still require apparatus but require less physical space because they can be boxed and stacked. Sets of equipment can be split up and hosted in several smaller locations that would not otherwise be used for teaching or research laboratories, such as cupboards, bookshelves, corridors, mezzanines, and basements.

Because of the inherent safety that is designed into NTPW, staff are no longer needed to over-see every hour of practical work, and this allows a significant extension of the time students can meaningfully engage with the laboratories, by being able to engage outside of the traditional setting as well as within in it. Currently, many traditional laboratory courses are pushed for time, so students are brought in to a strict schedule, taught as much as possible in the allotted time, then they must leave quickly to let the next group in.

The inherent timetabling flexibility also opens new opportunities for interdisciplinary project working, with cross-year student teams. This is highly desirable because professional engineering practice does not take place wholly in silos. Cross-year

project groups can be found in Design programmes, where the students form a design agency led by the older students and staffed by the younger students, who pitch for work from clients that include course staff and external (genuine) clients [5]. A similar approach is attractive to engineering, and NTPW offers a route to delivering this experience.

NTPW is also more than a lower-cost replacement for traditional practical work because it has been shown to offer equal or better outcomes [6]. The causes of the improved outcomes are at least in part because of affordances that cannot typically be reproduced in traditional settings, such as visualising invisible fields. Optimum educational outcomes appear to be obtained when traditional laboratories are retained, and students benefit from a mixture of the approaches rather than relying on either approach alone [7].

3   CURRICULUM CONTRIBUTION

3.1 Guiding self-exploration

One of the challenges discovered in adapting problem-based learning (PBL) to engineering is that it requires the students to direct their own study of the material. This can be risky in such an exact, technical and hierarchical subject where concepts built on 'wrong knowledge' are harmful [2]. This implies a need for even smaller groups, and more direction from the staff, ensuring that the required mathematical and physical knowledge is in place. This can make PBL in engineering either prohibitively expensive or risky. While PBL is primarily focused on students acquiring cognitive knowledge, similar principles presumably apply to students undertaking self-directed study in the application and integration of knowledge, such as during PjBL. How then to make staff sufficiently available throughout the extended duration PjBL (weeks or months), where student activity is not constrained to office hours?

A post-humanist [8] approach provides a fruitful ground for appreciating the potential in this space. By adopting a viewpoint in which non-human agents, such as technological artefacts, are of equal status to human participants, critical post-humanist approaches offer a refreshing perspective, particularly because they emphasise that technology should be valued on its own terms, rather than on how well it can replace humans [9]. As Edwards [10] points out, the 'post' in post-human is not anti-humanistic: "*it is not 'after' in terms of going beyond, but in terms of offering a constant experimentation with or questioning of the human*". Bayne's exploration of using a chatbot to interact with students on a digital humanities course motivated us to see that NTPW activities are potential collaborative partners that could bring their own agency to bear in assisting student learning [9] by fulfilling some teacher-like functions, such as hinting, guiding or even challenging students.

NTPW activities have hardware and software designs that naturally set a scope for the exploration that students can undertake, but within that scope there should be room to provoke students to think about surprising and unexpected results, and explore different sets or variations of parameters without rushed to complete or having to worry

about being negatively judged for the particular route of their learning journey. The values of a malleable intelligence (such as exploring and practicing) are desirable, and can be communicated by NTPW activities. However, these activities should not be countermanded by the presence of a step-by-step procedural lab sheet, but instead encouraged by the actions of the teacher-like functions. There is already the potential for a significant amount of hinting and guidance that can be embedded in the user interface.

User interface design then takes on renewed pedagogical importance, as opposed to being driven purely by aesthetic or usability requirements. Students receive both intended and unintended messages in traditional work, and the same holds true for NTPW. Without understanding the hidden messages being transmitted by the interfaces, there could be inconsistences from one part of an interface to another, between experiments, or between the interface and any artificially-intelligent communication capability. Getting this right could well mean multiple design and interaction languages to cater to different degrees of open-ended-ness. This is a key motivation for a shared software infrastructure, so as to reduce duplication of effort.

As the students move to more senior years, user interfaces should become more open-ended. For project work, activities might be programmed directly by the student and/or the data analysed in Jupyter notebooks [11]. On this journey from school-like bounded environments, to work-like open-ended environments, the interplay between students, NTPW activities and staff can be viewed as an educational collaboration.

Taking a posthuman perspective can help us further interrogate this teacher-like effect of non-human NTPW intermediaries on student practices.

3.2 Developing professional practices

Graduates are destined to enter a world in which social and technological aspects are intertwined. They must navigate professional practice that will take place in environments that educators will struggle to predict. This challenges the idea that best practice is a 'thing' that should be solidified, static, or final. This immediately provides a tension against the idea of a having a fixed behaviour that we are trying to teach a student within a given activity. Therefore, a diversity of solutions should be expected in a NTPW activity, within bounds that are set only as tightly as needed for the coherence of the overall programme of study. It also has consequences for conceiving of the social, and material, construction of the learning that takes place through NTPW practices.

Although definitions of practice are often contested [12], we follow Schatzki's definition of practices as "*embodied, materially mediated arrays of human activity centrally organized around shared practical understanding*" [13]. A crucial element of this definition is the notion of practices as being '*materially mediated*'; that is, we cannot understand practice without considering the role of non-human actors in everyday human activities. *Practice* is widely cited as being integral to issues of knowing and learning at work, via the notion of '*communities of practice*' (CoP) [14]. When

newcomers come to practise a particular practice, they do so primarily through interaction with others who are experienced. Knowledge and learning are thus increasingly understood as socially constructed, where newcomers learn social and cultural practices through apprentice-style learning from older colleagues.

This is an issue for professionals working in emerging engineering industries because, due to the relative newness of the industry, there is a lack of expertise from longer-serving employees who legitimise references to past knowledge practices. Given the rapid pace of development in industry, it is increasingly likely that graduates will find themselves in this situation. So, how can engineers in emerging industries learn from others if the practices and knowledge are yet to be developed, or are changing so rapidly they fail to stabilise? In this case the term '*community of practice*' is better transposed as '*practices of community*' [13]. That is, rather than a community existing *a priori*, containing the knowledge and determining the activities, the latter term foregrounds the activities as generating a community, which is precariously held together by people, relations and materials.

What then can be done in higher education to provide experience of this? Subject knowledge has been chosen for its long-term relevance, and staff are authorities, so it cannot be done in the existing curriculum. We argue that NTPW activities offer a rapid refresh and update cycle (unlike conventional laboratories), which opens the way to giving students experiences with leading edge technological concepts, and to observe the behaviour of senior students, tutors, and staff when handling newer concepts themselves, before the concepts and practices around those technologies have stabilised.

4   IMPLEMENTATION, EVALUATION AND SUPPORT

4.1 Implementation

Academic participants from three UK Universities are actively engaged in comparing institutional drivers, barriers, and challenges. This has already generated a variety of use cases and externalities, such as differing commitments and operational policies (e.g., information security). All three institutions involved have identified a need for NTPW across all modalities, and a desire to move beyond treating NTPW interventions on a separate basis.

In order to support the kinds of learning described above, we require an interoperable infrastructure that works across institutions, which brings together all forms of NPTW in a consistent manner. This is intended to lower the barrier to usage of NTPW by course organisers who are not software developers. This implies integration with learning management systems, and federated authentication. Since learning management systems differ from institution to institution, LTI integration would be an obvious choice to consider, and the latest version (LTI 1.3 Advantage) offers some opportunities to present an "app store" of experiments for integration.

Booking and management functions would be required for synchronous remote laboratory experiments and other modalities will have their own variation of use cases,

for example, virtual laboratories may contain datasets that range from openly accessible, to those that are restricted to a few or one student. A common or interoperable approach to data provenance, micro-payments, evaluation, grading and feedback will also be required.

We expect that our individual institutions may want the option of hosting the services themselves or outsourcing them. This suggests multiple, individually-complete NTPW services that may serve one or more campuses, and that can interoperate with each other to share activities and services, or pool equipment.

This overall set of requirements suggests favouring microservice-based architectures, with discovery and federation, which are able to be extended by adding new microservices as required. We are currently working on developing the architectural design of an initial prototype of this system, beginning with a minimum viable set of features and evolving the infrastructure and interfaces in response to feedback from staff, students, and developers.

4.2 Evaluation

Evaluation of student learning outcomes due to NTPW will be difficult to separate from other interrelated aspects of the curriculum in which it is embedded. Student exam performance before and after the introduction of specific NTPW activities will be affected by year-on-year variation in student cohorts, and limited to assessing cognitive aspects. Cognitive aspects are only a subset of learning evaluation. The performative skills should result in a change in the affective domain, which can be assessed by surveys with a greater or lesser degree of reliability in the self-reporting. Well-constructed NTPW activities will contribute to shifting students away from a fixed model of intelligence, typically developed by the teach-to-the-test mindset prevalent in secondary education. Tests that indicate the adoption of a malleable view of intelligence can give an indication of the development of graduate attributes that are better suited to coping with professional practice. A more insightful approach would be to run focus groups to collect qualitative evidence. That evidence could also assist in posing and prioritising future developments

Over a longer period of five to ten years, we would expect to see a change in the behaviour of graduates as reported by employers, and by comparing qualitative statements from students about their first few years of their careers. This would require a longitudinal study, so as to capture views from current students who will have had less exposure to NTPW both before they leave, and after they enter the workforce. These could be complemented by surveys on 21 attitudinal scales and through the development of a question bank that is intended to elicit student views on issues relating to professional skills. These can be combined with interviews with academic staff and tutors on their impressions, and potentially ethnographic study as appropriate.

In terms of assessing students, a specific example of how assessment strategies could change in light of our discussion in Section 3 is that a diversity of solutions within the

class could be foregrounded and explicitly valued as a component of the mark. Then, there is no longer the implicit assumption that the best way to get good marks is to figure out which is the solution favoured by the teacher.

Student feedback is ripe for enhancement, by moving to a model where students are able to access feedback on demand. A straightforward example is providing a service to which students can submit work for feedback on the aspects that can be deterministically calculated (e.g., waveform shown on graph is as expected or not). We also expect to see benefits in this area from teacher-in-the-loop automation [15], where AI approaches are used to label student interactions. These approaches surface triaged information for the attention of the teacher, which could be modified to present carefully contextualised and scaffolded comments that can prompt the student. The teacher can then act on the information, or not, according to their judgement of what the student will benefit from most. Current developments focus on open-ended environments with well-defined actions. Further developments are needed in this area to accommodate NTPW activities in which the interaction is via programming or involves interacting with analogue data.

We also envisage adapting this approach to track and analyse the short-term cause and effect of any interventions by AI within the experiments, thus contributing to the overall activity evaluations as well as individual student performances.

4.3 Staff support

Delivering new NTPW experiments to prepare students for professions where practices have not stabilised (Section 3.2) will require a change in mindset; to reject the comfort of re-delivering familiar material year on year. Teachers will inevitably require support in developing and delivering these activities, scaffolding student expectations, developing appropriate assessment strategies, and having these approved in regulations and accredited.

Existing academics are not expected to develop new digital literacies sufficient to turn them into content creators, although this practice is encouraged where appropriate to the individual's interests and experience. Given the specialised nature of digital artefact generation and remixing, with all the edge cases, security implications, and performance/maintenance implications, then the required expertise is not trivial. For those who do not already work with coding in some way, the barrier and investment is likely to be too high to overcome.

In the first instance, academic colleagues would access pre-existing activities. When it becomes necessary to customise or remix those activities, or create entirely new ones, then an appropriate model can already be found in the existing traditional laboratory ecosystem. Traditional campuses often run a mechanical workshop with a team of designers, fitters, turners, and machiners, and laboratories themselves are often overseen by dedicated technicians who understand the relationship between the pedagogical approaches and the laboratory apparatus. There is no reason to assume that this model would not work in the case of NTPW, with the mechanical and electrical

workshops continuing to provide physical structures, whilst a team of software developers, with a mixture of capabilities, would handle the translation of academic ideas into activities, and manage the reliable delivery of them.

These developers would likely benefit from community interaction with their opposite numbers at other institutions. The best vision imagines annual conferences or workshops to share their experiences and practices, as well as various digital means that are ubiquitous in open-source projects. Versions of these events internal to institutions would be relevant to academics interested in contributing, as well as new developers, and experienced developers who work in different disciplines across campus. Usage of NTPW is envisaged not just in engineering, but broadly across campus.

5 CONCLUSION

The burden of producing large cohorts of engineering graduates who are well prepared for their future careers can now only be met by a substantial infusion of NTPW into coursework and, eventually, assessment. The economic and pedagogical arguments are both in support of this because adding new NTPW activities costs less than increasing the traditional practical work provision, and opens up new ways of learning that were not previously possible. Academic staff can be assured that NTPW is intended as a complement and extension to traditional practical work, and that existing traditional practical work provision must be retained in order for students to achieve the best educational outcomes. Teacher-like functionality emerges in NTPW activities beginning with the interface and hardware design and, viewed through a *post-humanistic* lens, is seen to complement rather than compete with academic staff, because technical artefacts do not replace humans but instead have their own value to offer. Institutional support is ultimately necessary, but more affordable and better value than the alternative of increasing only the traditional practical work offering. The pooled infrastructure we envisage permits a phased adoption that is further de-risked by adapting developments in response to ongoing evaluation, with *practices of community* emerging to support academics, those in new support and development roles specific to NTPW, and student co-creators.

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