Crisis and catalyst

The impact of COVID-19 on global practice in engineering education

Dr Ruth Graham

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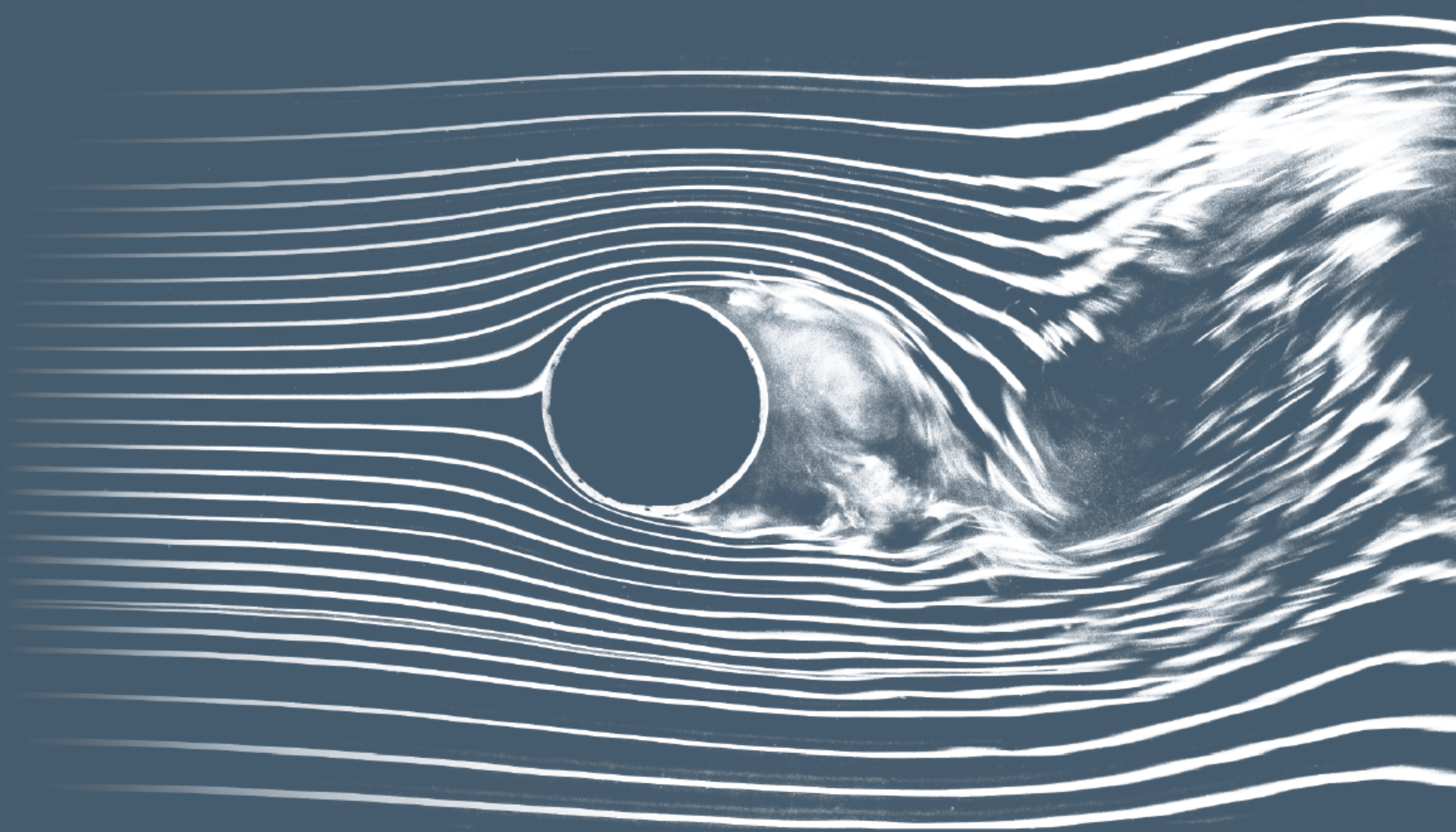

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Executive summary

The decade leading up to 2020 was a period of fundamental change in engineering education. It saw the emergence of a new generation of globally-recognised programmes that took an experiential and collaborative approach to learning, underpinned by face-to-face problem solving.

In early 2020, the COVID-19 pandemic prompted an immediate pivot to online learning for universities worldwide – including those planning or delivering such innovative programmes. As the engineering education community grappled with the challenges of this period of emergency teaching (ET), it was also confronting questions about how to deliver student-centred, collaborative learning experiences remotely. Hand-in-hand with these questions was the wider issue of the longer-term impact of COVID-19 and ET on the future trajectory of the sector and the innovative emergent practices of cutting-edge engineering programmes.

Informed by the perspectives and experiences of the global engineering education community, the *Crisis and Catalyst* study takes stock of the sector-wide impact of ET. It addresses two central questions:

1. What were the experiences of the engineering education community <u>during</u> emergency teaching?
2. How will this systemic shock impact the direction of travel for the sector <u>beyond</u> emergency teaching?

The study draws on interviews conducted between August 2020 and April 2022 with university leaders, engineering instructors/faculty, educational specialists and engineering students. The 226 interviewees were located in 36 countries, spread across six continents. Interviews were conducted on the basis of anonymity; quotes included in the report are therefore unattributed. Examples of educational innovation developed or delivered during the period of ET are included throughout the report.

1. What were the experiences of the engineering education community during emergency teaching?

ET represented a system-wide shock to the engineering education sector. It was abrupt and unforeseen, and it destabilised practices, priorities and cultures that had been deeply embedded in engineering programmes for decades.

ET was also noted to have exposed and exacerbated major challenges facing engineering education. Two stood out. The first was **inequalities in digital access**. Of particular concern was how students without a dedicated place to work, reliable internet access, and a smart device were denied access to much of the learning opportunities and communities of support available to their peers. The second was **wellbeing**. The combined impact of increased workloads, social isolation and uncertainty about the future took a heavy toll on the mental wellbeing of students and instructors alike. So, for example, the sudden switch to online learning left many students feeling overwhelmed by the amount of new information they needed to manage at a time when they were struggling to foster meaningful connections with peers. A range of interventions were rolled out by engineering programmes to address these challenges, such as the adoption of activities to foster student-to-student empathy and promote peer connectivity across the physically-dislocated student cohort.

While acknowledging the long shadow cast by these challenges, interviewees also characterised ET as an unprecedented time of educational experimentation and collaboration. Supporting student learning and wellbeing were quickly established as the explicit and primary priorities of university leaders at all levels of the institutional hierarchy, opening up new opportunities and resources for educational reform at a course and programmatic level. At the same time, ET brought into focus the weaknesses of teacher-centred pedagogies for many instructors that had hitherto taken a lecture-based approach to their teaching. Student engagement during transmissive online 'lectures' was often low, with many turning off web-cams and reluctant to ask questions during synchronous sessions. With limited opportunities for peer-to-peer interaction, teacher-centred pedagogies also exacerbated student isolation, with few opportunities to build trusting and collegial relationships with peers in the online environment. As a result, the online pivot catalysed a fundamental change in the pedagogical approach of many engineering instructors. It was a change that often came in two stages: the rapid redesign of courses for online delivery and then, in the months that followed, the incorporation of active, collaborative and/or blended learning as mechanisms to address growing concerns about student isolation, overwork and wellbeing.

Experiences across this two-staged process prompted many instructors to reconsider the aims, structure and learning modes for their courses, often working for the first time with educational developers to embed active learning pedagogies. A wealth of new pedagogical ideas and practices emerged, ranging from the development of novel kits-of-parts for student to engage in hands-on learning from home, to the use of low-stakes online graded quizzes in place of written proctored exams. ET also saw increased numbers of instructors embrace team teaching as a mechanism to meet the wide-ranging demands of online and blended learning. Such developments were often informed and advanced by new communities of support brokered with the regional and global engineering education community.

ET was also noted to be a time that forged a new connectivity between students and instructors, as they together navigated the challenges and uncertainties of this unprecedented period. Indeed, many instructors went onto describe how this experience had given them a new insight into the lives of their students and had thrown into sharp relief inequalities that had not previous been visible. The experience was one that brought social responsibility to the fore, with an increasing recognition of the diversity of barriers faced by the student community. Awareness was heightened by the movement for racial equality catalysed in the US and gaining wider global support from 2020. As a result, some interviewees, particularly those based in the US, reported that the most passionate and far-reaching conversations across their academic community during ET centred around diversity, equity and inclusion.

In the transition out of ET, interviewees consistently noted their relief and joy at the opportunity to re-establish in-person learning and interaction. They spoke at length about how the online pivot had underscored the importance of in-person connectivity and hands-on engagement for student wellbeing and engineering learning as well as the unique role played by the university campus in enabling such transformations. Indeed, many interviewees pointed to wide-ranging debates precipitated by ET at their universities on how the campus footprint should be used to add most value to student learning and development. At the same time, it was widely acknowledged that the flexibility offered by blended learning and remote working had been embraced by the university community with a strong and vocal expectation from students that many 'taught' engineering courses would continue to be delivered online.

2. How will the systemic shock of COVID-19 and emergency teaching impact the direction of travel for the sector?

Interviewee feedback made clear that COVID-19 and ET would re-chart the trajectory of the engineering education sector. The next generation of leading programmes will undoubtedly embed educational cultures and practices that were tested, refined and/or catalysed during ET. Taken together, interviewee reflections on the influence of COVID-19 and ET on the cutting edge of engineering education point to two major long-term effects. As outlined below, these are: **(i) precipitating new directions** for the sector; and **(ii) accelerating trends already in train** prior to 2020, respectively.

i. Precipitating new directions for engineering education

ET was noted to have catalysed new cultures, priorities and practices in many engineering schools and universities across the sector. Although often long advocated in the pedagogical research literature and appearing in pockets of good practice, such approaches were unlikely to have emerged or been embraced at scale but for the systemic shock of ET.

ET prompted instructors and university leaders alike to confront fundamental questions – and challenge deep-rooted assumptions – about the purpose and place of engineering education in the 21st century. It exposed the weaknesses of teacher-centred pedagogies – particularly with respect to student engagement and peer-to-peer connectivity – and precipitated a step-change in attitudes and practices amongst a significant minority of instructors towards **active and collaborative learning**. For many in this group, the extended period of ET had served to embed these changes to cultures and practices. For example, in recognition of the benefits they afford to instructor flexibility and student support, it was anticipated that **diverse teaching teams** would become increasingly evident in coming decades, with undergraduate teaching assistants playing an active role. In addition, the root-and branch reform of **assessment practices** precipitated by ET was expected to lay the foundations for a more diverse and dynamic approach to assessment across the sector, with approaches such as group projects and one-to-one oral exams playing a more prominent role.

At the same time, ET brought the issue of **student mental health** to the fore, with strategies to enhance wellbeing often placed at the heart of programme-wide responses to COVID-19. The idea that engineering schools should play an active role in fostering student wellbeing was noted to represent a profound change and one would be retained at many institutions in the future. ET was also noted to have had a far-reaching impact on educational strategies in many universities. For example, building on the rapid, agile and community-informed approach to educational decision-making that emerged at many universities during ET, it was anticipated that **co-produced educational strategies** – drawing on in-house expertise and pedagogical research – were likely to play a more prominent role in shaping institutional policies for teaching and learning in the future.

ii. Accelerating trends already in train prior to 2020

Interviewee feedback suggested that ET would accelerate and enhance many of the cultures, priorities and practices already under discussion or implementation in engineering programmes prior to 2020. The online pivot provided an opportunity for universities and instructors alike to 'stress test' new educational approaches – and the infrastructure needed to support them – at a scale that had never been imagined. It also worked to demonstrate the role and value of many evidence-based practices to instructors and students alike. So, for example, the online pivot both validated the benefits of **blended learning** and enabled its acceptance across the academic community. ET also appears likely to accelerate a trend towards programme-wide blended approaches that emerged in the years leading up to 2020, in which all technical engineering learning is disaggregated into online 'micro modules' that students access independently to help them address on-campus team-based challenges. At the same time, ET fast-tracked the development of the **digital infrastructure** and amassed the asynchronous learning resources needed to enable such large-scale adoptions of blended learning.

Stemming from a wider adoption of **flexible learning pathways** and student choice, interviewees also anticipated that engineering schools and universities would increasingly establish **programme-wide scaffolding** to ensure that all students progressively build a core set of professional competencies over time. Another prominent theme was **social justice**, with the experiences of 2020 and 2021 expected to foster a greater emphasis on social responsibility in both engineering curricula and the wider culture in engineering schools.

In anticipating the direction of travel for leading engineering programmes, interviewees cautioned that a positive sector-wide post-ET transformation was by no means inevitable. Instead, interviewees were clear that the changes outlined above would likely be restricted to well-resourced universities already operating at the cutting-edge of engineering education and/or those that took an agile and community-led approach to navigating ET. Interviewees based outside such institutions often took a much more pessimistic view of their institution's future trajectory, and particularly its capacity to drive positive change or to engage instructors to support such efforts.

Their pessimism spoke to a wider concern among interviewees – across institutions and countries – that the period of ET would drive the further stratification of the engineering education sector. ET exposed and exacerbated inequalities within the student community, among university staff and between institutions and countries. Interviewees noted that the resources to mitigate these impacts are also unequally distributed. For many universities, the lack of institutional resources closed off opportunities for innovation both during and after ET. Conversely, institutions with the resources to invest in a new generation of educational technologies and specialist staff were now well-positioned to take leading roles in the sector.

A related concern was that, in an increasingly competitive higher education market, some institutions and programmes will emerge from ET with a culture in which students – their learning, advancement and wellbeing – are not a central priority. ET was characterised as a time when speed of deployment often took precedence over the quality of student learning in the rush to deliver online courses and activities. As a result, much of the online learning delivered worldwide during this time was passive and teacher-centred. While of questionable benefit to student learning, such forms of online education are also quick and cheap to deliver: without costly experiential, interactive or mentorship elements and without the need for on-campus spaces, such online 'lectures' can be scaled up to almost any student cohort size, offering a significant cost savings to universities. Without a clear set of educational values underpinning the use of digital learning, deep concerns were voiced about the proliferation of such forms of online learning and the impact this might have on students' learning, mental wellbeing and communities of support. Interviewees also cautioned that, while ET represented a time of unprecedented change across higher education, for many universities, these changes were simply a temporary response to a crisis situation. As a result, it was suggested that some of the potential benefits of practices adopted during ET would not be fully realised. There may therefore only be a narrow window of time to enable evidence-based and long-term change before many institutions revert to the pre-2020 status quo.

However, despite the concerns expressed about the barriers and risks facing the engineering education sector, most interviewees sounded an optimistic note for the future. The consensus view was that, while ET has undoubtedly been a period of **crisis** – placing unprecedented demands on the sector and testing its adaptive capacity – it will also act as a **catalyst** for a new generation of leading engineering programmes in which the opportunities, learning and wellbeing of students are placed at the forefront.

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Names and affiliations of study Advisory Group members:

- Jorge Baier: Pontifical Catholic University of Chile, Chile
- Antoine van den Beemt: 4TU Centre for Engineering Education and Eindhoven University of Technology, Netherlands
- Jaime Bonilla-Ríos: Tecnológico de Monterrey, Mexico
- Lori Breslow: Massachusetts Institute of Technology (MIT), US
- Ed Crawley: Massachusetts Institute of Technology (MIT), US
- Pierre Dillenbourg: Swiss Federal Institute of Technology Lausanne (EPFL), Switzerland
- Geir Egil Dahle Øien: Norwegian University of Science and Technology (NTNU), Norway
- Anette Kolmos: Aalborg University, Denmark
- Rhys Morgan: Royal Academy of Engineering, UK
- Pey Kin Leong: Singapore University of Technology and Design (SUTD), Singapore
- Emanuela Tilley: University College London (UCL), UK
- Jessica Townsend: Olin College of Engineering, US

Contents

List of acronyms used in the report

AR	Augmented reality
DEI	Diversity, equity and inclusion
ET	Emergency teaching
MOOC	Massive open online course
PBL	Problem-based learning
PjBL	Project-based learning
VR	Virtual reality
ASU	Arizona State University, US
CSU	Charles Sturt University, Australia
EPFL	Swiss Federal Institute of Technology Lausanne, Switzerland
KTH	KTH Royal Institute of Technology, Sweden
MIT	Massachusetts Institute of Technology, US
MTU	Munster Technological University, Ireland
NTNU	Norwegian University of Science and Technology, Norway
PUC	Pontifical Catholic University of Chile, Chile
SUTD	Singapore University of Technology and Design, Singapore
Tec de Monterrey	Tecnológico de Monterrey, Mexico
TU Delft	Delft University of Technology, the Netherlands
UCL	University College London, UK
UoG	University of Georgia, US
UTM	Universiti Teknologi Malaysia, Malaysia
ViMEET	Vishwaniketan Institute of Management Entrepreneurship and Engineering Technology, India

1. Introduction

1.1. Study context and focus

The decade leading up to 2020 was a transformative period for engineering education. As described in the 2018 MIT-commissioned report on the global state of the art in engineering education[1], a new generation of globally-recognised engineering programmes emerged that took an experiential and collaborative approach to learning. While some established online platforms for learning core engineering science principles, the pedagogical approach was underpinned by synchronous, face-to-face interaction and collaboration, often through immersing students in authentic engineering problems.

The COVID-19 pandemic prompted an immediate pivot to online learning for universities worldwide – including those delivering, or aspiring to deliver, such innovative programmes. They were forced to confront the question: how is it possible to deliver student-centred, collaborative learning experiences remotely? Hand-in-hand with this question is the wider issue of the long-term impact of COVID-19 and the resulting period of 'emergency teaching' (ET) on the future trajectory of the engineering education sector and the innovative emergent practices of cutting-edge engineering programmes[2].

As universities look to formulate a longer-term educational vision beyond ET, a global benchmarking study was launched. Drawing on interviews with members of the global engineering education community, it addresses two central questions:

1. What were the experiences of the engineering education community during ET?
2. How will this systemic shock impact the direction of travel for the sector beyond ET?

The study was designed around two outputs, both of which are open source. The **first** is this *Crisis and Catalyst* report, which explores feedback from across the global engineering education community on the experience of ET and how it might impact the trajectory of the sector in the future. The **second** is a series of in-depth case studies which explore the institutional response to ET at six[3] of the universities identified in the 2018 MIT report as 'emerging leaders' in engineering education. Each case study describes one 'best practice' example of collaborative engineering learning that was delivered partially or fully online at the university during ET. These case studies are available at the project website[4].

The study is supported and co-funded by a consortium of engineering schools and universities[5]. The study was led and undertaken by an independent higher education consultant. Further details of her background and experience can be found at her website, www.rhgraham.org.

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[1] Graham, R. (2018). The global state of the art in engineering education. *MIT Report, Massachusetts, USA*

[2] The term ET is used throughout the report to describe the educational approaches that were rapidly developed and delivered in response to COVID-19 restrictions, including online/remote learning, blended, hybrid and socially-distanced in-person learning

[3] The six institutions are: Singapore University of Technology and Design (SUTD), Singapore; Aalborg University, Denmark; Massachusetts Institute of Technology (MIT), US; Pontifical Catholic University of Chile (PUC), Chile; University College London (UCL), UK; and Iron Range Engineering, US

[4] Collaborative Engineering Education in the Digital AGE (CEEDA) website: www.ceeda.org

[5] The 11 study co-funders are: Aalborg University, Denmark; Swiss Federal Institute of Technology Lausanne (EPFL), Switzerland; MIT, US; Norwegian University of Science and Technology (NTNU), Norway; Olin College of Engineering, US; PUC, Chile; Royal Academy of Engineering, UK; SUTD, Singapore; Tecnológico de Monterrey (Tec de Monterrey), Mexico; UCL, UK; and 4TU Centre for Engineering Education, The Netherlands

1.2. Study approach

The study was conducted between August 2020 and April 2022 and draws on one-to-one interviews with university/engineering school leaders, engineering instructors (faculty, lecturers, teaching assistants, etc.), educational specialists (educational developers, instructional designers, engineering education researchers, etc.), engineering students (including recent graduates), and other partners (e.g. from industry, the regional community or external educational support agencies) from across the world. In all, one-to-one interviews were conducted with 226 individuals from 36 countries. Figure 1 provides a regional breakdown of interviewees by continent of their affiliated university/organisation and by role. Anonymity was protected; interviews took place on the understanding that no information or opinions would be attributed to named individuals in the report unless explicit permission was given. The interviewees consulted for the 21 case studies included in the report were given the opportunity to review and approve the text prior to its inclusion.

Taken together, interviewee feedback provides a detailed picture of the experiences, perceptions and expectations of the global engineering education community.

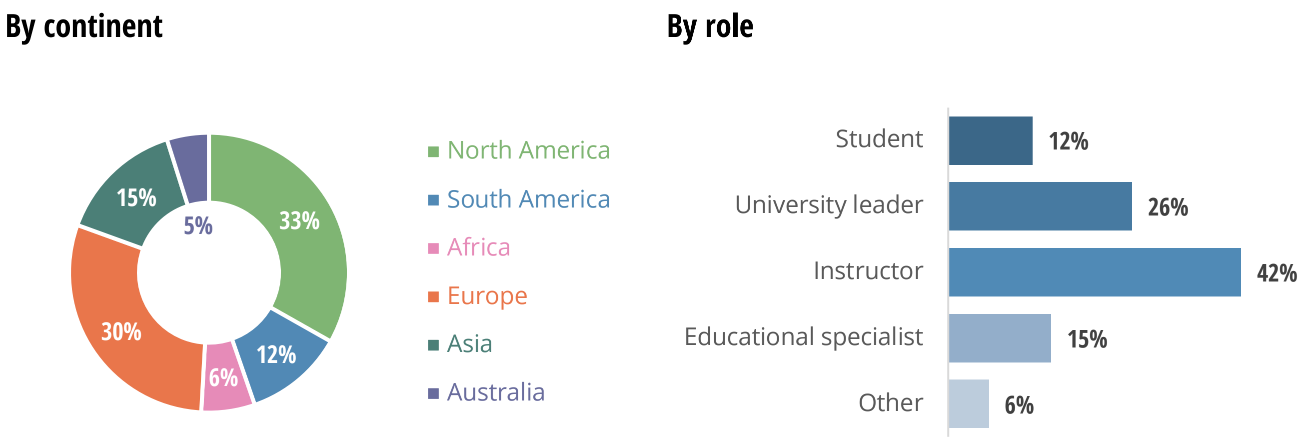

Figure 1. Breakdown of interviewees (n=226) by continent and role

Further methodological details of the study are given in Appendix A. It should be noted that, although a range of stakeholders to engineering programmes worldwide was consulted, the dominant groups were instructors (including faculty members, teaching assistants, and lecturers) and leaders of engineering departments, schools and universities. The in-depth case studies taken from six engineering schools and universities worldwide – as presented on the project website[4] – are designed to provide particular insight into the student experience of ET.

Quotes from the interviewees are used throughout the report to illustrate the themes that emerged.

At the time when interviews were held, almost all respondents had participated in predominantly face-to-face teaching (prior to COVID-19 restrictions) and fully online teaching (during COVID-19 restrictions). In addition, almost half of interviewees had also engaged in some form of hybrid teaching, typically as their institution transitioned out of ET conditions.

It should also be noted that this report focuses on the experiences, priorities and expectations of the engineering education community. However, the findings are likely to have wider applicability across all higher education disciplines.

1.3. Structure of the report

The report is structured across two major sections, Sections A and B, as outlined below. The opening chapter of Section A (Chapter 2) charts the experiences of interviewees chronologically across the first two years of ET (from early 2020 to early 2022) and is designed to set a context for themes discussed throughout the rest of the report. Each subsequent chapter is structured around topics consistently raised by interviewees.

SECTION A. COVID-19 EMERGENCY TEACHING: the practices, challenges and lessons learnt for the engineering education community during ET, exploring:

Chapter 2. **The emergency teaching experience:** the experiences and milestones of engineering schools worldwide during ET from early 2020 to early 2022.

Chapter 3. **Major challenges faced:** key challenges faced during ET, including inequality of digital access and mental wellbeing of both staff and students.

Chapter 4. **Emerging cultures and practices:** educational innovations and developments that emerged during ET, such as changes to assessment practices or hands-on learning.

Chapter 5. **Lessons learnt for online learning:** a synthesis of the advice and reflections offered by interviewees on how and when to deliver engineering learning online.

SECTION B. BEYOND EMERGENCY TEACHING: the anticipated long-term legacy of ET on priorities and best practices across the engineering education sector, as well as risks faced, exploring:

Chapter 6. **New directions for the sector:** priorities, practices and cultures that were noted to have been triggered or enabled by the experience of COVID-19 and ET.

Chapter 7. **Acceleration of existing trends:** ways in which COVID-19 and ET were noted to have accelerated changes already under discussion or implementation prior to 2020.

Chapter 8. **Concerns and risks for the future:** anticipated risks and challenges facing the engineering education sector that stem from the experience of COVID-19 and ET.

The report closes with a chapter that offers concluding comments. Please note that many of the themes included in the report Chapters are strongly interlinked. So, for example, concerns about student wellbeing and social isolation (Section 3.2) during ET were strongly linked to resultant changes in assessment practices (Section 6.3) and the greater priority likely to be given by engineering schools to competencies such as empathy and student wellbeing in the future (Section 6.4).

Short case studies are used throughout the report to illustrate how the themes are reflected in engineering schools and universities across the world. A list of these short case studies is given in Appendix B.

Please note that the report draws only on feedback from members of the global engineering education community as captured via one-to-one interviews.

SECTION A.
COVID-19 EMERGENCY TEACHING

This Section focuses on the period of ET introduced at universities worldwide from March 2020 due to COVID-19 restrictions, exploring the experiences and lessons learnt for the engineering education sector during this unprecedented period. Taking the key milestones of ET chronologically, Chapter 2 charts and signposts many of the challenges, practices and priorities that are subsequently explored in more depth in the report.

Specifically, this Section explores:

- **The emergency teaching experience (Chapter 2):** the experiences of ET, taken from the perspective of engineering schools and instructors, and the strategies developed to navigate this period of rapid change and uncertainty.
- **Major challenges faced (Chapter 3):** key challenges faced during ET that were most consistently identified by interviewees, principally equality of digital access and the wellbeing of students and staff.
- **Emerging practices and cultures (Chapter 4):** major changes to educational cultures and pedagogical practices that emerged in engineering schools and universities during ET.
- **Lessons learnt for online learning (Chapter 5):** synthesis of interviewee feedback on the lessons learnt for the delivery of engineering teaching and learning online.

ET restrictions in place in engineering schools and universities worldwide

On 11th March 2020, the World Health Organisation declared the outbreak of the COVID-19 virus to be a global pandemic. In response, social distancing restrictions were imposed worldwide, often restricting citizens to their homes or immediate neighbourhoods.

Study interviewees were asked to describe the ET restrictions imposed at their engineering school or university between March 2020 and April 2022. Their feedback pointed to considerable variation in the type and duration of the restrictions by university and region. They ranged from universities that operated in an exclusively online mode for almost two years, through to those that had retained some level of face-to-face teaching throughout ET, albeit under social distancing regulations. Most interviewees, however, described operating in a fully online/remote mode for 9-15 months, typically starting in mid-March 2020, following by extended period of blended and hybrid teaching. At most institutions, a portion of students were able to return to on-campus halls of residence before face-to-face teaching resumed, from where they were able to engage in their engineering learning online, using on-site internet access.

2. The emergency teaching experience

Chapter summary

This Chapter charts chronologically the four key phases of ET and its impact on engineering education from early 2020 to early 2022 as reported by interviewees, offering context for the themes explored in later Chapters of the report:

Section 2.1. Immediate response: the response in the days following the announcement that the university would be pivoting to ET (typically in mid-March 2020).

Section 2.2. Pivoting to emergency teaching: the response during the first semester of ET following the online pivot (typically from March until June 2020).

Section 2.3. Embedding remote learning: the response adopted during the 2020/21 academic year, which was predominantly delivered online (typically July 2020 to June 2021).

Section 2.3. Transitioning from emergency teaching: the response during the 2021/22 academic year, in the gradual transition away from ET (typically from Aug 2021).

2.1. Immediate response

When reflecting on the experience of ET, interviewees often described a series of distinct phases, each associated with its own milestones, challenges and emotional responses. The first of these phases was short – typically between two days and two weeks – and covered the period between the announcement of imminent COVID-19 restrictions and the recommencement of undergraduate teaching under ET conditions. For most, this hiatus occurred in the middle of March 2020. Almost all pivoted to a fully online delivery mode.

The hours and days following the announcement of the 'online pivot' were noted to be a time of shock and bewilderment. As one interviewee recalled: *"I remember it vividly, nobody quite knew what to expect… I was in the lab in a studio session when the announcement was made and people were watching their phones saying that everyone was to go home"*. It was also noted to be a time when *"we had all of us incomplete information, ambiguous information and uncertainty"*, with unanswered questions ranging from what health impact COVID-19 might have on the university community to *"whether full-scale online teaching was even going to be possible"*. In the words of one instructor:

> *"we had no idea how many students were going to be able to show up for [remote] class, we had no idea what their family situations would be and how that would affect their academic engagement… I think a lot of the challenge in that space was partly just a sense of calibration".*

After the immediate concern with *"making sure everyone was safe"*, the main priority was *"getting the technology up and running"*. Interviewee feedback pointed to sharp differences by institution in both the quality of existing IT infrastructure to support online learning and the capacity of instructors to operate effectively in such modes. Regardless of their starting point, however, most interviewees went on to suggest that *"we had a history of underinvestment in our digital estate"*. As a result, the announcement of the online pivot marked the start of *"a mad scramble to sort out our IT infrastructure"* with particular focus on how to enable simultaneous connection of large student numbers to the university learning management system (LMS) and securing site licences for critical software. Attention also turned to ensuring that students and instructors had the hardware they needed to connect and work online by, in some cases, giving or loaning them items such as microphones, web-cams, iPads and laptops.

Alongside these institutional efforts to improve the digital infrastructure and access, significant work was undertaken to help instructors and students prepare for the online pivot:

- **support for instructors**: offering training and support in both the practicalities of online teaching (e.g. how to record and upload videos) and the principles of designing active learning online. At some institutions, undergraduate teaching assistants (UGTAs) were engaged to support the transition to ET. For example, at the Universidad de los Andes (Uniandes) in Colombia, around 400 UGTAs were trained to provide one-to-one support to 600 professors to design course interfaces on the LMS and develop interactive online learning resources.
- **support for students:** providing support, resources and training to students to help them to navigate ET, both academically and personally. For example, the support systems offered to MIT students included a website[6] to guide their remote learning, one-to-one weekly coaching sessions (for which 550 staff, administrators and instructors volunteered to become coaches during ET), and a framework[7] to help students and instructors identify the level of risk associated with different hands-on activities when undertaken from home.

At institutions where news of the online pivot broke during a vacation period, where no subsequent return to campus was possible, interviewees often noted that *"the community was fragmented and the communication lines were breaking down"* during this time. In contrast, many who had the opportunity to make some preparations while physically on campus pointed to key benefits afforded, including to: (i) offer students a 'dry run' of the online learning experience so that instructors could address in person any issues faced; (ii) give students kits of materials and tools to enable them to complete hands-on projects at home; and (iii) hold celebration events for students unlikely to return to campus prior to graduation, such as the impromptu early graduation ceremony held at Olin College of Engineering[8].

Instructors and leaders also spoke about how their roles fundamentally changed as a result of the new responsibilities they assumed during this time: *"now you become a health and safety officer, a newscaster, a therapist… [supporting] students financially, academically, psychologically".* For many, this shift in role was immediate and continued throughout ET.

2.2. **Pivoting to emergency teaching**

The second major phase of ET was consistently identified as the period from March to June/July 2020, typically the remaining months of the semester disrupted by the online pivot. This period was characterised as one where *"we were all just surviving. A lot of that was trying stuff out and just hanging on for dear life"*. A major focus for leaders and instructors was *"giving the students a semblance of normality"* in their engineering learning, under a backdrop of growing concern about the impact of emergency teaching on students' mental wellbeing and (in some cases) academic development.

The phase was also one in which education and the student experience were noted to be the *"number one topic of conversation"* across all levels of the university hierarchy (see Section 4.5). A major priority during this time, and throughout ET, was to understand the experiences of staff and students as they

[6] MIT, Best practices for remote learning: https://learnremote.mit.edu
[7] MIT, Remote Making: https://wikis.mit.edu/confluence/display/make/Remote+Making
[8] Olin College 'fauxmencement' 2020: https://www.olin.edu/blogs/congratulations-class-2020

navigated remote working and responded to the various challenges faced. A range of mechanisms was used to capture community feedback including online platforms, such as *Unitu*[9], online surveys and virtual 'town hall' meetings. Often responding directly to concerns raised, university and school leaders were called upon to make rapid and far-reaching decisions around educational policies and priorities throughout this time. It was consistently noted that addressing the issues faced during ET – in areas ranging from scaling-up IT infrastructure to rolling-out new mental health support services – called for a collaborative decision-making approach that brought together expertise and representation from across the institution. Ad-hoc, community-informed decision-making committees quickly emerged at many universities that played a major role in shaping the response to ET at both a school and institutional level (Section 6.6).

One major focus for early discussion and decision-making was assessment. For many engineering schools and universities, the online pivot was timed immediately before the end-of-year assessments that typically centred on written invigilated exams. A variety of approaches was adopted to navigate this major assessment period. Some sought to *"retain the integrity"* of timed written exams through the use of online proctoring. Others sought to minimise the emphasis on 'high stakes' assessment by offering alternative, simplified assessment systems. All, however, saw rapid and systemic change to an element of the engineering programme that has often remained fundamentally unchanged for many decades (see Section 4.3). The experience also prompted a major community-wide debate around the purpose of assessment in engineering education that continued throughout and beyond ET and, for some, appears likely to yield new attitudes to assessment years to come (Section 6.3).

Some interviewees pointed to an ongoing piloting of new educational ideas and online tools during this phase of ET. There was also, however, an acknowledgement that *"that first wave of ET was very much just electrifying the lecture"* for many engineering courses, with *"students literally stuck in front of their screens for days on end"* watching pre-recorded or synchronous 'lectures' with limited interaction with instructors or peers. Much of the educational experimentation in these early weeks was therefore focused on *"trying everything we can to maximise the interactivity"* through, for example, piloting various online 'chat' and feedback tools to connect students and foster cross-community dialogue. Many instructors also pointed to the pivotal role played by UGTAs in both helping them to design engaging and student-centred online learning experiences, and acting as an intermediary for relating students' experiences and concerns to course leaders. Interviewees often went on to note that *"a lot was learnt during those early months"* about how to support and engage students online. As explored further in Section 5.1, they noted several ways in which the online delivery mode offered new opportunities for connectivity and information exchange with students, such as through securing external 'virtual' guest speakers or engaging students in cross-community 'chats forums' to offer peer learning and support.

Despite these *"bright spots"*, however, the community also faced deep-rooted challenges during this phase of ET. The mental wellbeing of both students and staff was noted to be *"a real worry to a lot of us"*. In addition, while acknowledging that *"it was out of necessity"*, concerns were also expressed about the quality of many of the courses delivered during this early phase: *"the success metric was we did it. It was not, we did it well"*. As one professor noted at the time:

> *"I'm amazed at what people have actually accomplished in the terms of ET. I think just switching from Friday to Monday and having online classes ready really is quite amazing. But I think there's a lot of work still to be done in upgrading the pedagogy".*

[9] Unitu: https://unitu.co.uk

2.3. **Embedding remote learning**

The third phase of ET was typically identified as the 2020/21 academic year. While academic calendars vary worldwide, for most interviewees this began around August 2020. While the early months of ET were characterised as *"reactive"*, the approach taken to online educational design and delivery in this third phase was often noted to be *"more intentional"*. However, exhaustion, social isolation and excessive workloads amongst staff and students continued to be major concerns.

For many instructors, plans for the new semester were made under "*a cloud of uncertainty*" about the likely type and duration of ET restrictions that would be imposed for the coming academic year. As a result, many were compelled to prepare their courses for a range of different delivery modes:

> *"you make three versions, a completely on-campus, a hybrid and a completely online, and in developing the three versions, none of them is I think optimised, but you also develop them in a way that you can easily swap from one to the other… depending on what the regulations ask us to do".*

While some instructors had hoped to *"kick everything like labs or practicals down the line"* in the expectation that ET restrictions would be short-lived, it soon became clear to many that *"the entire 2020/21 session was going to be different, and almost certainly all online"*. In response, some instructors and schools took the decision to enable a step-change in their approach to emergency online teaching in preparation for the 2020/21 academic year. Many went on to contrast the early months of ET, that were described as *"just about survival"*, with the more proactive and evidence-led approaches to online learning adopted during this new semester. It was also noted that student expectations for their experience as engineering learners had also increased: *"we understood that the first half year [of ET] was a compromise, it was an emergency, but now you must be better prepared, so we expect higher quality"*.

As explored below, these efforts to enable fundamental improvement to the quality and impact of ET were noted at both the engineering **school** and the engineering **instructor** levels.

At the **engineering school level**, the drive to *"upgrade our online provision"* for the 2020/21 academic year was often underpinned by strategies to foster evidence-led pedagogies and new communities of practice. In some cases, these efforts were supported by strategic investment in 'flag-ship' online courses used as exemplars to inspire similar changes elsewhere. One example, from UCL in the UK, is given in Box 1. The new approaches often also benefitted from the recruitment of new cadres of educational developers, teaching assistants, and/or educational technologists. These investments came in addition to continuous improvements seen at many engineering schools during this period, including to IT infrastructure, digital tools, and mentoring/support systems for both students and staff.

At the **individual instructor level**, a surprising number spoke about how they had dedicated the pre-semester vacation to a root-and-branch reform to the structure, focus and/or pedagogical approach of their courses. Some were driven by the need to *"rectify bad experiences"* faced in the early months of ET. However, some instructors also took the opportunity of the online pivot to address some of the weaknesses that had long plagued their engineering programmes and had been exacerbated during ET. They typically pointed to one or more of the following priorities as being key drivers for reform:

- ***improving wellbeing:*** student wellbeing was noted as a major and ongoing concern that, in the words of one department head, *"we had swept under the rug for so long, but COVID has really brought that to the forefront"*. In efforts to address this issue, as explored in Section 3.2, many of the educational reforms enabled during this period focused on: (i) helping students to manage workloads; (ii) fostering peer connectivity; and (iii) improving students' mental health.

- ***offering hands-on learning:*** when it became clear that ET would likely extend across the full 2020/21 academic year, considerable effort was focused on enabling or replacing hands-on engineering learning experiences for students to undertake remotely, as explored in Section 4.2. In one example, outlined in Box 2, 'digital twins' were used to replace hands-on labs and projects that had been planned as part of a major curricular reform at McMaster University.
- ***fostering active and collaborative learning:*** it was noted that the early months of ET had seen many instructors *"falling back into a traditional lecture-based set-up"* and brought into focus the dominance of transmissive pedagogies in engineering programmes world-wide. In a bid to *"get away from students staring silently at Zoom all day"*, many instructors implemented sweeping changes to their courses in order to embed active and collaborative learning (see Section 4.1).

Most interviewees who enabled systemic reforms to their courses during this time went on to report that *"I am not going back"*, indicating that the changes would become permanent course features. Many such educational reforms were characterised as *"personally energising"* and ones that brokered new

Box 1: **Strategies for change, UCL Engineering, UK**

Theme highlighted: **Strategies to foster student-led, active online learning**

Preparations for remote delivery of undergraduate programmes at UCL's engineering school (UCL Engineering) in the 2020/21 academic year were guided by two broad strategies – the **first** driven by the university and the **second** driven by the school – as outlined below. Further details of the approach taken by UCL Engineering during ET are given in the case study on the project website[4].

The **first strategy** was to establish a clear benchmark for what constitutes minimum acceptable practice for online education at UCL and to offer targeted support to instructors to meet this threshold. In April 2020, UCL launched the *Connected Learning Baseline*[10] which provides a checklist of features that embody good practice in online education. A suite of resources was put in place to assist instructors to meet this Baseline. These included an asynchronous professional development course in online learning and the appointment of *Connected Learning Leads* in each department to coordinate the development of discipline-specific digital learning resources. At the same time, UCL Engineering established the *Learning Technology Unit* (LTU) to offer strategic advice for school leaders and provide *"a one-stop-shop for information and help"* for instructors in the transition to online teaching. Accessed via a dedicated website[11], much of the support offered by the LTU focused on helping instructors to meet the Baseline, including training in online learning, technical advice, and pedagogical guidance.

The **second strategy** to support the online pivot was specific to UCL Engineering. It involved facilitating the development of exemplars in online education that went beyond the Baseline, to catalyse more ambitious change across the school. Departments were each asked to identify two courses that would become such exemplars – termed 'gold' courses – which were joined by three common courses from the Integrated Engineering Programme[12] (IEP) that bring together all students in UCL Engineering. The leaders of each 'gold' course received support from the LTU to optimise their structure and pedagogy, including: a six-week training course in active online learning; a dedicated LTU consultant to support course design; and a student assistant. A major focus for 'gold' courses was to embed an active and collaborative approach throughout the synchronous and asynchronous activities. One such IEP 'gold' course was *Mathematics Modelling and Analysis 1*, taken by all 1000 first-year students in the school, as described in more detail in a case study on the CEEDA website[4].

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[10] Connected Learning Baseline: https://www.ucl.ac.uk/teaching-learning/publications/2021/sep/ucl-connected-learning-baseline

[11] Learning Technology Unit, UCL Engineering: https://www.uclengltu.com

[12] Integrated Engineering Programme: https://www.ucl.ac.uk/engineering/study/undergraduate/how-we-teach

connectivity across programmes and departments. Despite this sense of optimism from some, interviewee feedback pointed to two major challenges facing the community during this period. The **first** was the combined effects of *"overwhelming exhaustion"*, derived from sustained high workloads and *"long hours and days on Zoom"*, and the stress of operation in an 'emergency mode' for over a year with ongoing isolation and uncertainty about the future. The physical and psychological toll of these factors was a consistent theme raised throughout the duration of the study and across all interviewee groups. The **second** issue only emerged when considering interviewee feedback in aggregate. Taken together, they painted a worrying picture of stratification across several dimensions of engineering education, where existing inequalities were exacerbated by the pandemic. Two stood out. One was the inequalities of digital access that left some engineering students almost completely excluded from learning for a large portion of ET (Section 3.1). The other was the stratification of engineering schools and universities worldwide, with some able to leverage additional resources and expertise in ways likely to catalyse positive change in areas such as student flexibility, access and engagement, while others, without access to such resources, saw a calcification of educational reform efforts during this period, often accompanied by a regression to teacher-centred pedagogies (Chapter 8).

2.4. **Transitioning from emergency teaching**

The fourth phase of ET was typically noted to start in August 2021, often timed at the beginning of the 2021/22 academic year. Although experiences varied by region and by cycles of new COVID-19 restrictions, for many interviewees, this period marked the start of a gradual transition from a predominantly remote/online educational delivery. For many, this was the first time that the full academic community had been able to return to campus. It was also characterised as a period of reflection on the long-term impact ET on engineering education, which was tempered by ongoing uncertainty about what challenges may be faced in the months and years to come.

Interviewees consistently described their *"relief and joy"* at the full return to their university campus and being able to *"reconnect with students and colleagues"* in a way that had not been possible for 18 months, albeit with social distancing restrictions in place. Serendipitous social interactions, hands-on learning in on-site maker-spaces, and *"just having fun"* were all features of the on-campus experience that had proved problematic to recreate online and were sorely missed. Indeed, one major theme of interviewee feedback was the ways in which ET had laid bare the importance of the university campus and *"the power of the in-person experience"* for brokering identity, connectivity and engagement across the student community. Many went on to argue for the need to *"use face-to-face a lot more intentionally"* in the design and delivery of engineering programmes in the future, as explored in Section 6.5.

While campuses had often re-opened, many engineering programmes were still operating under stringent social distancing regulations, often with restrictions on the numbers of students that could engage in person at any time. As a result, hybrid learning – simultaneously engaging some students in-person and some students online – was widely adopted. As discussed in Section 6.5, a range of strongly-held views was expressed about the success and impact of hybrid during this period. One element that many agreed on, however, was the step change in the quality and impact of the technologies used to support hybrid learning over the course of ET. As one professor noted:

> *"our technology has advanced to be way better than it was when the pandemic started... [where we had one in-class stationary] camera to deliver a talking head... Now we have cameras that track, so I can walk around the classroom and have an interactive experience and not at the suffering of the online students... there are [microphones that] now drop from the ceiling where now you can hear the students*

> *in the classroom asking their questions, so I don't have to repeat it for those folks that are on Zoom. So it's just changed so rapidly.... Now I can focus on the actual learning part of it".*

Another major theme of interviewee feedback was how the experience of COVID-19 and ET might impact future priorities, practices and cultures in engineering education. Beyond the use of campus spaces, ET has clearly been a catalyst for many to confront fundamental questions about the purpose and place of engineering education on the 21st century. Many interviewees went on to point to evaluations and strategic reviews that had been launched at their institutions to explore such questions. The first of these reviews started to deliver their findings in late 2021 and early 2022. They tended to fall into one of three categories:

1. ***lessons learnt from ET:*** designed to identify effective educational practices developed during ET that offered potential for propagation, such as the three task forces commissioned at the Swiss Federal Institute of Technology Lausanne (EPFL) in Switzerland to explore lessons learnt in: hybrid teaching; project-based learning; and the first-year experience. The four Dutch technical universities also launched several studies that explore the lessons learnt from ET[13].
2. ***horizon scan focused on education*****:** designed to chart the university's future educational priorities based on the academic community's experiences of and reflections on ET. One example is the *Future of Education* review at KTH Royal Institute of Technology (KTH), Sweden whose priorities included enabling a diversity of assessment practices and developing new learning spaces that promote active and collaborative learning.
3. ***horizon scan for all university activities:*** designed to review and revise the university's strategic priorities in all spheres of academic activity. For example, *Task Force 2021 and Beyond*[14] was established at MIT to examine the lessons learnt from COVID-19 and chart a future direction for the university, drawing on input from 11 working groups split across four workstreams: (i) academic; (ii) administrative; (ii) finance and data; and (iv) community and culture.

Interviewee feedback made clear that many in the engineering education community anticipate major sector-wide changes that stem from the experiences of ET and COVID-19. As highlighted in Chapters 6 and 7, these anticipated changes span areas ranging from assessment practices to the prominence of social justice in the curriculum. Within this landscape of anticipated change, interviewees pointed to several factors that are likely to work against positive reform. Two were consistently highlighted. The **first** was establishing a momentum for ongoing change at a time when the academic community was *"absolutely on our knees with exhaustion"*. In particular, some cautioned that a conflict existed between, on one hand, the overwhelming drive for the university community to "*get back to normal*" and, on the other hand, the desire to explore and embed lessons learnt from ET. For some, without "*real momentum*" and targeted lobbying to identify and retain good practices, educational approaches could default to the status-quo and *"revert to how things were before the pandemic"*. The **second** risk was the ongoing uncertainty about what the future might hold: *"this element of uncertainty in anything that you do, itself is a very big risk. At every stage, whether you are at policy making level or you are at regulation level, or you are at delivery... uncertainty is everywhere"*. In addition to what future COVID-19 restrictions might be imposed, interviewees noted ongoing uncertainty over the long-term effect of the pandemic in areas ranging from the priorities of engineering employers to the mental health of staff and students. So, while largely optimistic about the future, interviewees consistently noted that their views on future priorities, practices and cultures in engineering education were often clouded by uncertainty.

[13] 4TU: Centre for Engineering Education, Innovation Map: https://www.4tu.nl/cee/innovation/

[14] MIT Task Force 2021 and Beyond: https://tf2021.mit.edu

Box 2: The Pivot, McMaster University, Canada

Theme highlighted: **Digital alternatives to hands-on learning**

In March 2019, the Faculty of Engineering at McMaster announced that it would be rolling out a root-and-branch reform of its undergraduate education. Called 'The Pivot'[15], this educational transformation would take a human-centred approach and focus on interdisciplinary and experiential problem-solving. The new curriculum would be built around a spine of hands-on project-based learning experiences contextualised around real-world industrial and societal challenges.

An early focus of the Pivot was the launch of the *Integrated Cornerstone Design Projects in Engineering* (1P13), a year-long course for all 1100 first-year McMaster engineering students that replaced four separate courses in materials science, programming, computer-aided design and professional practice. 1P13 is framed around a series of team-based projects (in applications ranging from renewable energy to healthcare) that become increasingly complex and open-ended as the course progresses. All components of 1P13 – including labs, design studios and lectures – are delivered in the context of these authentic projects, as a mechanism for students to advance their ideas, knowledge and understanding.

In preparation for the launch of 1P13 in September 2020, McMaster worked with the external company Quanser to prepare over 100 physical devices – such as robotic arms and mobile robots – to be used by student teams in several of the projects that punctuate the course. For example, one project was to design a robotic system that sorts waste products for recycling, and Quanser provided a robotic manipulator arm[16], supported by custom software, to guide and support the student learning. These devices were designed not only for use in students' projects, but also to support the learning of specific engineering principles during lab classes. So, for example, while students are engaged with the holistic project of sorting recycled items, parallel lab sessions focus on related concepts and skills such as: motor control; understanding sensors; or programming skills (to enable students to write a piece of code to manipulate the robotic arm).

Following the shift to ET in March 2020, it quickly became apparent that the Pivot's inaugural student cohort would be engaging with both the 1P13 course and their team-mates remotely. In the six months that followed, Quanser and McMaster worked together to develop 'digital twins' of each of the physical devices: virtual simulations that would offer the same functionality and control as their physical counterpart. For example, the digital twin for the recycling project provided a virtual simulation that allowed students to sort objects by type and deposit them into appropriate bins for disposal using the same embedded computers and code they would have used with the physical systems.

Following the launch of the Pivot in September 2020, over 1000 first-year students engaged with the digital twins as part of their remote 1P13 projects and lab experiences. Instructor feedback suggested that these experiences were associated with high student engagement, with the digital twins providing a valuable tool for students to explore the engineering design process and advance their ideas.

As it transitions beyond ET, McMaster Engineering will place both digital twins and physical devices at the heart of IP13. This blend of the virtual and physical is seen to offer three particular benefits. Firstly, it was noted to mirror authentic modes of working of graduate engineers. Secondly, this approach offers new opportunities for students to model and test their ideas in a virtual environment before coming to the lab to explore and advance their designs in the physical setting. Thirdly, the use of digital twins can be used to enhance the online portfolios developed by the students throughout 1P13, which they can use as a digital record of their learning and achievements when pursuing co-ops, internships and other opportunities both within and outside of the university.

[15] The Pivot: https://www.eng.mcmaster.ca/about/pivot
[16] Quanser Manipulator Arm for Robotics Courses and Research: https://www.quanser.com/products/qarm/

3. **Major challenges faced**

Chapter summary:

Interviewees were asked to identify the major challenges faced during the period of ET at their school or institution. This Chapter outlines the three challenges most frequently raised by interviewees and often noted to be ones for which no effective long-term solution had been found. The Chapter closes with a summary of other challenges that were also raised repeatedly:

Section 3.1. Equality of digital access: the quality of the institutional IT infrastructure and the capacity of students to access IT devices and reliable internet during ET.

Section 3.2. Student mental wellbeing and social isolation: the wellbeing of students as they engaged with and self-managed their learning at a time of physically isolation from peers.

Section 3.3. Staff mental wellbeing: the toll taken on instructors and university leaders from prolonged uncertainty and exhaustion during the months and years of ET.

Section 3.4. Other challenges: other challenges faced by engineering schools and universities during ET, such as ensuring data privacy and limitations around student recruitment.

It should be noted that this report focuses on engineering education, exploring the experiences and issues raised by stakeholders during interview. It therefore does not address the wider impact of COVID-19 on the academic community, or the broader logistical and support challenges addressed by many universities during the pandemic, such as administering COVID-19 testing.

3.1. **Equality of digital access**

In universities worldwide, the pivot to online learning raised immediate questions around access to digital learning. This centred particularly around two questions: (i) can the university's IT infrastructure (including IT staffing) support a rapid transition to and sustained delivery of online learning?; and (ii) does the whole student community have reliable access to power, the internet and a computer or smart device (such as a smart phone or tablet) when learning remotely? Almost all interviewees spoke about some level of challenge at their university in relation to both questions. Their feedback, however, also pointed to stark inequalities in the extent to which these challenges were overcome.

Almost all interviewees reported that their university transitioned to fully online delivery – for all degree programmes and all students – in early 2020. Many also noted that their institution's IT infrastructure was *"nowhere near where it needed to be to support that volume of online learning"*, particularly during the early months of ET. However, while some spoke of *"frantic activity and investment in the first half of 2020"* to acquire site licences for software, to build the IT infrastructure and to recruit new IT support personnel, other interviewees noted that *"it was very difficult for us to make any significant change in terms of infrastructure because of availability of funds"*. This latter group of interviewees spoke about how their institutions lacked the resources to purchase, for example, commercially-available LMSs or video-conference tools such as Zoom. Indeed, several noted that COVID-19 restrictions precipitated a sharp fall in their university teaching budget due to the numbers of students unable to pay tuition fees. In some cases, this led to a wave of redundancies amongst teaching and support staff. In the words of one: *"COVID had already pushed a lot of people below the poverty line. It was not possible for us to ask for* *anything extra… in two years, the complete economics of the institution [were] taken apart"*. Interviewees in this group often went on to note therefore that the IT support systems and infrastructure at their institutions remained largely unchanged throughout the period of ET which led to significant constraints placed on both the creation and accessing of online learning materials.

While IT infrastructure was clearly a significant challenge, the major focus of interviewee feedback in this area centred on the capacity of students to access online learning. A striking proportion of instructors spoke about how ET had offered them a new insight into the lives of their students and had thrown into sharp relief inequalities that had not previous been visible: *"you can see the difference right there… some students obviously have everything they need to study from home, whereas [for] others, their living conditions were such that they couldn't connect"*. This inequality appeared to be particular acute around reliable access to power and the internet, and/or access to a computer/smart device, without which, in the words of one interviewee, *"the students were completely stuck, their education was completely lost"*. Interviewee feedback suggested that, in countries worldwide, a significant minority of students were unable to access some portion of their education during the early months of the pandemic. Many in this group were connecting via devices shared with family members and/or were relying on intermittent internet access which, in turn, left them struggling to access synchronous classes and connect with peers and instructors using a web-cam. Several instructors pointed to challenges that they faced at this time to design learning experiences that *"offer an equal experience for all students, regardless of their internet connectivity"*.

Interviewee feedback suggested that many engineering schools and universities were able to address these access challenges relatively quickly and effectively in the months following the online pivot, often through adopting one or more of the following strategies:

- **opening on-campus 'dorms-rooms':** many universities allowed students back into internet-enabled on-campus accommodation from which to engage in online learning;
- **delivering learning asynchronously:** some institutions asked instructors to prepare asynchronous materials, or record any 'live' sessions, so that students with unreliable internet connections can *"access it whenever they have a high bandwidth, for example, at night"*;
- **supplying devices:** many institutions offered smart devices/computers to students. For example, MIT loaned iPads to students and Nairobi University offered laptops to students;
- **supplying data:** some institutions, such as the University of Pretoria, allocated students a monthly data allowance to enable or improve internet access. At a national level, the Chinese government was noted to have called upon *"state-owned telecom operators to guarantee network coverage, especially in remote areas, and to reduce or waive telecommunication service fees"*.

Other institutions, however, simply did not have the capacity or resources to adopt such measures. Interviewees from regions in Asia and Africa, in particular, suggested that a significant proportion of students (as high as 90% in one case) relied on shared family smart devices and mobile hotspots to access learning, or else had no access to online learning at all, throughout ET. As ET progressed and postal services resumed, some institutions *"sent students basic books and notes, so that they can read and get prepared for the examinations"*. Some also gave permission for student groups to travel to campus for short periods to take examinations, access workshop facilities, engage in intensive 'catch-up' courses, or to use the internet to download resources onto their smart phone or laptop, before returning home. Others facilitated peer-to-peer connections between students located in the same area, such that they could share devices and/or internet connectivity to access learning resources, submit assignments, and engage in projects and synchronous classes. As one interviewee explained, *"when the COVID pandemic was a little bit lessened... then the students could reach to another student's home, where there is connectivity and where there is a mobile phone available, and they completed their work together"*. One innovative example of such a peer-to-peer approach is given in Box 3.

Such strategies and interventions, however, were not available to all engineering students and some continued to have little or no access to their engineering programmes throughout ET. In many cases this appears to have had a catastrophic impact on their academic development, with students often dropping out or *"pausing their studies for one or two years"*. As one instructor commented:

> *"unfortunately, [only] the students who had ownership of a laptop could do the projects properly, and other students just followed them. That was an impact, and that is why specifically they lost these two years, they could not have good project experiences... and then when they came into the universities for final mark sheets and in examinations, they could not speak, because they didn't do anything. [If] you cannot have access to the physical facilities, [and] you do not have money to buy a computer, [and] you do not have a facility to complete the projects, the only thing you can contribute is a theory, nothing else. They could not do anything, even during the examinations".*

Box 3: **The Internet of Things, Vishwaniketan Institute, India**

Theme highlighted: **Addressing equality of digital access**

The Vishwaniketan Institute of Management Entrepreneurship and Engineering Technology (ViMEET) is an engineering-specialist university based in the Maharashtra state of India. A significant minority of ViMEET's students are drawn from rural regions of the state. Following the university's pivot to online learning in March 2020, it soon became clear that many of these students were struggling to access reliable internet connections and were instead relying on local mobile hotspots to access their learning. For such students, accessing synchronous sessions or collaborating online in real time with peers or team-mates often presented a particular challenge. A major priority for this period of ET was therefore to establish alternative mechanisms to foster active, collaborative and project-based learning across the student community.

The Internet of Things (IoT) was an existing non-credit-bearing optional course, offering students a project-based immersion in hands-on learning through the development and prototyping of internet-enabled devises in an on-campus workshop. Following the online pivot, the course leader, Professor Shilpa Shinde, implemented several adaptions to IoT to allow students to engage in team-based, hands-on learning while away from campus. Each participating student was sent a kit of parts containing an Arduino device and a set of linked components, such as motors and controllers. Drawing on either synchronous online workshops or written instructions, each student was asked to conduct simple experiments with their kit. Students then formed teams with peers located close by to pool their components and work in-person on a shared, common project: *"we clustered nearby students together, so they could meet each other, so they could enjoy teamwork"*. In addition to face-to-face, collaborative, and hands-on learning, this approach also facilitated the sharing of internet connectivity and access to smart devices or computers as students met (and sometimes stayed) in one another's homes.

During the 2020 and 2021 IoT courses, students were asked to develop devices that addressed some of the key challenges faced during the COVID-19 pandemic. Drawing on their kit of components, and other locally-sourced materials, the prototypes developed ranged from a 'sanitisation bot' that could be used to sterilise shared spaces, to a system that detected household gas leakage. With limited on-campus access throughout this period and few opportunities for hands-on learning, many participating students took their prototype developed during the IoT course as the basis for their subsequent final-year project.

3.2. **Student wellbeing and social isolation**

The challenge most consistently associated with ET – and raised by almost all 226 interviewees worldwide – was that of student mental wellbeing and isolation from peers. As one interviewee noted, *"the challenge that was really on our minds most in [March to May of 2020] and continued to be a central occupation is just understanding the mental health implications for our students"*. Indeed, many suggested that the true scale and nature of the effect of the pandemic and ET upon student mental health was unlikely to be fully understood for many years to come.

Mental health is widely understood to be a state of wellbeing in which an individual can cope with the normal stresses of life and continue to work productively[17]. Interviewee feedback suggested that, even before the pandemic and introduction of ET, the mental health of engineering students had been a growing concern. A range of specific stress factors was identified. Key amongst them was the high workloads and long contact hours often associated with engineering programmes. It was further noted that programme expectations and workloads have tended to increase in recent years as engineering schools and instructors responded for calls to build students' professional skills and mindsets in areas such as team-working or entrepreneurial thinking. These new activities and expectations, however, were noted to have been often *"piled on top of each other year after year"* onto existing programmes, without a strategic review of which elements might be removed, for fear of raising faculty concerns of *"dumbing down the curriculum"*. Some interviewees went on to suggest that pervasive cultures in engineering schools worldwide have also historically worked against efforts to highlight or address the mental health challenges faced by students. In particular, some pointed to *"an embedded ethos"* in many engineering schools that is built around a narrative that *"engineering is hardcore, we suffer and we take pride in suffering, the rest of the campus, they're all slackers… if you have a mental problem, that's a personal problem, and that's a personal failure and a personal weakness"*.

ET brought the issue of student mental health to the fore: *"this generation has an explosion of mental health problems to begin with, and then on top of that, the anxiety that has come with the pandemic. I have never seen so much anxiety in my classroom"*. Interviewees pointed to three primary factors that worked against student mental wellbeing, as listed below and discussed in the subsections that follow:

1. the challenge of understanding course expectations and managing workloads;
2. the challenge of building trusting, collegial and supportive relationships with peers;
3. the challenge of fostering motivation in their studies and combatting anxiety.

These three factors are interrelated, and the challenges and remedial actions described by interviewees often worked in combination across each. Some went on to suggest that, while some valuable interventions were rolled out to combat these challenges, many remained unresolved throughout ET.

3.2.1 **Understanding course expectations and managing workloads**

The first challenge facing students was "*understanding what was expected of them and being able to manage their workloads*" when studying remotely. Interviewees suggested that the sudden switch to online learning left many students feeling overwhelmed by the amount of information and new systems they needed to navigate. In the early months in particular, online education was often delivered via several different platforms, leading students *"to worry that they have might have missed a vital piece of information*

[17] World Health Organisation. *Promoting mental health: concepts, emerging evidence, practice (Summary Report)* Geneva: World Health Organisation; 2004

or missed a deadline". Interviewee feedback also suggested that the adoption of blended learning had, in some cases, increased students' workload as instructors created new asynchronous content to be completed in addition to existing synchronous timetabled sessions: *"for a lot of courses, we still have a two-hour lecture, plus all this additional video work, plus all these additional deadlines"*. While, at some engineering schools, *"there was an attempt to re-evaluate how much work is reasonable in a course"*, the net workload associated with many courses was often noted to be *"too high"*.

At the same time, it was suggested that ET imposed a radical change to *"the rhythm of academic life"* for students that affected their ability to plan, prioritise and manage their learning. This, in the words of one interviewee, often left students feeling *"overwhelmed and overworked"* at a time of physical isolation from peers and instructors. Interviewees pointed to the absence of informal interactions and out-of-class discussions that, when studying face-to-face, help students to both build awareness of course structure and identify the threshold concepts that are critical to their advancement. These interactions can include non-verbal cues picked up by students (such as *"those micro moments when you look at the person sitting next to you and they're not taking notes, so you know it's not important"*) and their instructors (*"the different ways that you find to explain the same thing to students when you can see from their body language that the team is a bit lost"*). Interviewees suggested that the online pivot often stripped these informal interactions from the students' learning experience. This was understood to leave many students unable to conceptualise the structure and expectations of their courses, as well as calibrate the relative priority of different course topics and activities: *"students are thinking everything is as important as everything else, and they're taking two hours to do an hour's worth of work, and they become completely overwhelmed because all they see each day is just more stuff to do and no respite"*.

Without these tacit signals from peers, interviewees described how students struggled to self-pace and to limit the time they spent working. As a result, some students were noted to be *"spending huge amounts of time on the material"* and often to an excessive degree. As one interviewee reported:

> *"we can see the amount of time students engage with the online material, and some of it's very frightening. Students watch videos over, and over, and over again. We've got a lot of data to say that some students are really doing too much… I think it's because we're asking these students to self-pace, and do all this learning on their own [but] we're not setting up boundaries to say how much is too much".*

Interviewee feedback suggested that, while these experiences may have led to high attainment amongst some students, they often also led to anxiety and exhaustion. A number expressed deep concerns about the long-term impact this may have on students' mental wellbeing.

Many interviewees went on to note that one of the key 'lessons learnt' from ET was the need to offer students greater structure, support and flexibility when they are engaging with their learning online. Some went on to reflect on how this approach may appear to run counter to the broader trend in engineering education to ask students to address ill-defined and open-ended problems, often as part of authentic team-based projects. However, as one interviewee noted, what was being advocated was to improve the *"clarity of expectations, not clarity of problems"* for students engaged online.

The strategies consistently advocated by interviewees to help students to schedule and manage their workload when learning online are outlined in 'Tip 4' in Section 5.3. These include: (i) clearly articulating to students the course expectations, structure and deliverables; and (ii) building students' capabilities in self-regulated learning through, for example, helping them to devise weekly learning plans.

3.2.2 **Building trusting, supportive and collegial relationships with peers**

The second challenge associated with student wellbeing was how to build trusting, supportive and collegial relationships with peers within a virtual learning environment. Interviewees suggested that in-person interaction has historically played a major role in fostering effective student-to-student collaboration and peer learning. The loss of this face-to-face community was keenly felt in several dimensions of the student learning experience.

One was in **groups projects**, and the levels of connectivity and collegiality established between team-mates. As explored in Section 5.2.2, without in-person opportunities to identify common interests and build trust, *"more conflicts than normal"* were experienced in project teams during ET. This issue was exacerbated by the increasing tendency of students to connect without web-cams switched on, such that peers were unable to see their faces: *"I used to drop in on every group [in breakout rooms] to just have a little look, and you hear that blinding silence – all the cameras are off"*. Indeed, some interviewees suggested that ET had laid bare the extent to which engineering programmes have not taken a systematic approach to building students' capabilities in effective team-working: *"when we talk about learning outcomes like 'working in diverse teams'… we have no idea what that means other than sitting [students] around a table having them do a project in a team and hoping that they learn teamwork"*.

Fostering meaningful connections **across the full student cohort** also proved difficult during ET. It was noted that synchronous sessions were often delivered to *"silence, with no faces to look at [due to web-cams being turned off] and no response from anyone"* with few students *"having the guts"* to ask questions in such a public forum. The absence of in-person interactions appeared to be felt most acutely by the cohort of first-year students, most of whom had yet to meet peer students face-to-face. These students, in particular, struggled to establish a peer community that could provide encouragement, inspiration and support through their studies. As one instructor noted:

> *"when working face-to-face… there is this culture of 'shared struggle', where everyone sits up all night to get things done, and work together to provide emotional support and technical guidance. That community has really disappeared [since moving online]. Students said that they felt they were the only ones struggling… the students just didn't see others struggling without that support community".*

While many engineering schools were quick to recognise the ways in which the online pivot had stifled student community and connectivity, many of the early remedial actions taken proved ineffective. Interviewees described how programme-wide social activities like 'online quiz nights' or 'drop-in coffee-and-chat sessions' often attracted few participants and generated limited cross-community interaction.

Such experiences often led to widespread reflection on the mechanisms by which students form meaningful and lasting connections during their engineering studies. What many concluded was that these networks were often underpinned by *"intellectual interactions rather than social interactions"*: the friendships and communities of support rooted in the shared experience of their engineering learning that help students to connect ideas, extend their thinking and spark new interests. Activities that blend the academic and social therefore featured prominently amongst the interventions recommended by interviewees to foster connectivity (as outlined in 'Tip 5' in Section 5.3). A second theme repeatedly raised by interviewees was the importance of fostering student-to-student empathy as a lever to building meaningful relationships while engaging with one another remotely in the online environment. A surprising number had amended their courses specifically to foster student empathy, often drawing on established models, such as outlined in Box 4.

While many such interventions helped to promote student connectivity and trust, it was noted that they often fell short of replicating students' face-to-face experiences. One critical missing element was 'unscripted' interactions: when online, almost all student-to-student and instructor-to-student interactions were pre-planned and pre-scheduled. In the words of one interviewee:

> *"every interaction has to be deliberate. There are no accidental interactions. And I don't think we've figured out how to do this [online]. How can you bring back those serendipitous interactions in a virtual environment? For me, that's the biggest challenge: the way everything now has to be planned".*

The online pivot brought into sharp relief the contribution of informal, non-scheduled on-campus peer interactions to students' learning and development: *"the informal chit-chat before the lecture or [walking] between buildings… interactions that create a community where they are learning together"*. Interviewees characterised these interactions as *"accidental"* and *"low stakes"*, bringing no fixed agenda or planned outcome, that emerge as a natural consequence of students sharing on-campus spaces, such as cafes or maker-spaces. Nonetheless, they were noted to provide the *"social glue"* that helped to broker trusting relationships and distinctive cultures and identities across student cohorts, beyond simply their project team or seminar group. The lack of these serendipitous student interactions was noted to be one of the major limitations of ET and was, in the words of one engineering dean, *"a problem that we are going to have to solve if we are going to think about large-scale online [learning] in the future"*.

Box 4: **Engineered Systems in Society, University of Georgia, US**

Theme highlighted: **Fostering empathy**

In a collaboration that brought together expertise in social work and engineering education, the *Engineering Education Transformations Institute* (EETI) research group at the University of Georgia (UGA) published a model in 2015 for understanding empathy in engineering. As the EETI director, Professor Joachim Walther, explained, the model framed empathy as a *"teachable"* competency that could be seen through the lens of three elements: *"it is a **skill**, the ability to see and appreciate other people's perspectives and engage around them, an **orientation**, that you're actually inclined to even do that, and then a **way of being**, that as an engineer I have a societal responsibility in my role"*.

Taking this model as a starting point, the interdisciplinary team went on to develop four 75-minute modules to foster empathetic communication amongst engineering students to improve their interactions with both peers and stakeholders. These four modules – focused on topics such as 'emotion regulation' and 'affective sharing' – have been embedded in the *Engineered Systems in Society*, a third-year mechanical engineering course at UGA that explores engineering problems in complex sociotechnical contexts. Following an introduction to the module topic, each module is structured around three activities:

1. **skills-building exercises:** building students' empathetic skills through small group exercises, such as finding out what they have in common with classmates unknown to them, or paraphrasing the experiences and perspectives expressed by others;
2. **engineering role-play:** applying these skills in an engineering scenario, *"for example talking to a stakeholder in the Flint Michigan case whose kids were dying from lead in the water…really experiencing some of those real-life real tensions and complexities around engineering ethics"*;
3. **debrief and reflection:** responding to a series of self-reflective questions about students' experiences and reactions during the module and the role played by empathy.

These exercises have been adapted and adopted by engineering schools worldwide, including during ET. For example, in 2020, a version of these modules was integrated into the first-year *Introduction to Professional Engineering* course at the University of Western Australia, taken by over 400 students.

3.2.3 **Fostering student motivation and combatting anxiety**

The third set of challenges to student wellbeing related to disengagement, loss of motivation and anxiety. While some students responded to ET by 'over-working' (as outlined in Section 3.2.1), others struggled to engage with their studies while learning remotely. As one engineering dean commented, *"student engagement dropped off a cliff when we went online".*

Interviewees consistently suggested that the online pivot stripped engineering programmes of many of the experiences that help to build students' motivation and contextualise their learning, such in-person meetings with project clients or developing prototype solutions in on-campus maker-spaces. As one interviewee noted, *"so many of the things that get students excited, that get them to class, that feed their energy are what is lost in the online space"*. In addition, a large proportion of engineering courses during ET took a teacher-centred and transmissive – 'learning by listening' – approach, particularly during the early months of the online pivot: *"a lot of people defaulted to reproducing what they would have done face-to-face which is turn [to] on the computer and read a lecture for an hour"*. Such courses typically offered limited opportunities for active or peer learning, particularly those with large student cohorts. Motivation, excitement and engagement in their studies could therefore be hard for students to sustain, often leading to low levels of participation in synchronous classes. The loneliness of online learning and the attendant increase in student anxiety added to the pressures on students.

At the same time, interviewees pointed to the acute difficulties faced by instructors in identifying students *"that are struggling, but are not saying anything"* within an online environment: *"it was just much, much harder to actually connect with students. Students who are having a hard time slipped through the cracks much more easily"*. As one teaching assistant commented:

> *"normally you can see those people in the classroom and you can go over to them and talk to them and help them, and they will engage with that. But it's much harder to get to those students [during fully online delivery]... because you don't have that in-person interaction, you cannot see their faces and if they won't ask questions, it's much harder to get to those students".*

Student interviewees similarly spoke about the challenge of connecting with peers when web-cams were switched off. One student contrasted their experience of productive, collaborative peer learning when assigned to groups where *"everyone was on camera"* to their experience working in one group where *"no one had their camera on, and no one spoke. We all just ended up working on our own in silence"*. As with so many of the challenges faced during ET, interviewees noted how these issues were exacerbated for new student cohorts who had not met face-to-face or previously engaged in collaborative and experiential on-campus activities prior to the online pivot. Many interviewees noted that both participation and engagement levels were lower for this student cohort.

Interviewee feedback pointed to several mechanisms that were developed and rolled out in their engineering schools or universities to address these challenges. As explored in 'Tip 6' in Section 5.3, many of these centred around *"having compassion for students"* and included: (i) offering individual attention to students in simple ways, such as using their name in 'chat' messages; (ii) embedding regular 'check-ins' with students to provide space for problems or questions to be aired; and (iii) incorporating activities to foster well-being into the daily schedule, such as mindfulness sessions.

It should be noted that separate processes were used to identify 'at-risk' students presenting with potential symptoms of acute anxiety and depression and directing them to professional support services.

3.3. **Staff wellbeing and isolation**

The experience of COVID-19 and ET did not only affect the mental wellbeing of students. A repeated theme of interviewee feedback was the profound mental health toll on engineering instructors, educational specialists and university leaders. Two words came up repeatedly.

The first was **exhaustion**:

- exhaustion from *"living in a constant state of emergency"* for two years;
- exhaustion from *"sitting in front of a Zoom screen all day"* often with no breaks during extended working days and working weeks;
- exhaustion from a *"completely overwhelming"* and sustained increase in workload throughout ET, *"the invisible labour of tending to student need"*, and the feeling that they are constantly *"standing on their heads to try to get the technology to work"*.

The second was **uncertainty**:

- uncertainty about whether and how ET restrictions might change week-by-week and the ongoing need to plan remedial actions for different eventualities;
- uncertainty about whether preparations made for online learning would work in practice, how students might respond, and how challenges faced might be rectified in real time;
- uncertainty about *"how the students are coping"* and if any were suffering from acute difficulties or *"struggling alone"* in a way that was not visible to the school or university.

Another theme repeatedly raised by instructors was the mental health toll of the ongoing compromises made to the quality of their teaching and learning as they worked to accommodate *"ever changing"* ET restrictions. Feedback pointed to an erosion of professional pride as many found themselves *"working 14-hour days"* only to deliver classes that they characterised as *"okay, but not great"*. As one faculty member commented, *"everything I am doing feels inadequate, nothing is quite right, everything's a compromise… it's not a very fulfilling way to teach"*. Several different strategies were adopted to "*cope with*" this ongoing challenge. Some spoke about how they leveraged support through team teaching, and sharing their experiences with colleagues and/or global communities of practice in engineering education. Others spoke of the importance of *"letting things go"*, often making explicit decisions to deprioritise activities that *"do not benefit the students"* and focus their time on areas where they are most equipped to add value. For example, one instructor spoke about how, throughout ET, she had divided her teaching activities into two groups: 'permanent changes' (that, while triggered by ET, would have long-term legacy) and 'temporary changes' (whose applicability was limited to ET). She went on to note that she had consciously focused her time and professional pride on the former set of activities: *"we need to accept that this is an emergency state, otherwise we will burn people out. I decided what I want to stay online forever, and not beat myself up if the 'temporary' online teaching is not perfect"*.

Some went on to note that although, for good reason, student mental wellbeing had been a major focus for support and resource across the sector, the mental health challenges faced by staff was often overlooked*: "there hasn't been enough focus on the faculty, on the lecturers, because they've took a lot of strain to keep everybody going during this time, they carried an enormous burden"*. Indeed, a significant minority of interviewees spoke explicitly about their own struggles with mental wellbeing and isolation during ET as the cumulative effects of professional challenges, isolation from colleagues, concerns about the health of friends and family, and additional caring responsibilities all took their toll.

3.4. **Other challenges**

Although the challenges most consistently raised by interviewees were those explored in Sections 3.1–3.3, others were also highlighted. Some relate to barriers associated with student assessment or with delivering active, collaborative, and/or hands-on learning, which are explored in Chapters 4 and 5. Other commonly-raised challenges are outlined below:

- **negative assumptions about online learning:** some interviewees spoke about the challenges associated with the assumption (from students, their parents, instructors and university administrators) that the experience of learning online will inevitably be worse than the 'gold standard' face-to-face experience. Some students, for example, entered university having had poor experiences of online learning at their high school where *"it was essentially just posting some reading assignments and homework problems on a website… no motivation, no engagement"*. Several interviewees spoke about ways in which they *"tried to get students out of this mindset that says 'this [online] experience is always going to be worse than being in-person'"*. For example, at Olin College, bespoke first-year workshops were held in 2020/21 to highlight areas where online learning offered advantages over the face-to-face equivalent, such as through the facilitation of digital surveys, the recording of interviews with user-groups, or digital prototyping/simulation.
- **data privacy:** several interviewees spoke about issues around data privacy laws and the constraints this placed on some digital learning and assessment option. These challenges appeared to be particularly acute for those based in the European Union, operating under GDPR[18] regulation. For example, in some countries, restrictions were placed on recording synchronous sessions in which students' faces or voices might appear without the explicit permission of each student concerned. For similar reasons, online exam proctoring systems in some institutions were unable to record videos of students, only monitor them in real time.
- **student recruitment and enrolment**: several issues were raised with respect to student recruitment and enrolment. At some institutions, COVID-19 restrictions served to drastically reduce enrolment numbers. For example, some smaller/newer programmes are highly reliant on face-to-face recruitment events to engage potential applicants, and attract and select students. Pivoting these events online often resulted in lower levels of engagement and, in consequence, applications. At the same time, other engineering schools saw large increases in enrolment numbers. For example, due to COVID-19 restrictions, the UK government opted to replace *A-levels* (the public exams taken by high school students prior to university enrolment) in 2020 and 2021 with grade predictions made by pupils' teachers. A consequence of this change was that a far greater proportion of prospective students achieved the grades needed to gain a place at UCL Engineering and the school's undergraduate intake numbers increased by nearly 50% in both of these intake years.
- **cross time-zone working:** with many students returning to their home region to continue their studies online, a widely-noted challenge was delivering synchronous classes and team-based experiences across multiple time zones. Many spoke about the conflict faced between the convenience of *"clustering students from the same time-zone together"* within the same project or class, and the desire to embed students within a globally-diverse peer group, with all of the cross-cultural awareness and breadth of learning that this brings.

[18] **General Data Protection Regulation** (GDPR) is an EU regulation governing personal data that relates to an identified or identifiable individual. Consent must be given by the individual to record, hold and process such data.

- **community-embedded projects**: many engineering student projects are focused on social development, built upon long-standing partnerships with regional community groups, charities or aid organisations. During the pandemic, many of these partner organisations were called to focus on their core business, and were therefore unable to support student projects or facilitate opportunities for students to connect with the communities they serve. In response, some engineering schools were forced to devise alternative projects during ET that were framed around the experience of the pandemic. Some replacement activities called upon students to tackle broader societal or medical challenges presented by COVID-19, while others responded directly to the challenges facing students while learning remotely such as *"how do we replace community; how do we stay connected; how do we find stuff to do".*

Three additional issues were also consistently raised, but there was no clear consensus across interviewees about the issue that they posed: to some, they presented major challenges, while to others they presented some level of benefit. These three issues are outlined below:

- **coverage of course content:** a range of views was expressed over the quality of learning and coverage of course content during ET. Some interviewees suggested that the capacity to re-watch asynchronous material had improved student learning. In addition, they noted that challenges posed by ET had enabled students to *"hit a whole new set of learning outcomes"* in areas such as digital skills and self-regulated learning. Other interviewees, however, expressed *"a grave concern over quality, over performance, over 'how do you know that the students are really learning?'"* during the period of ET. A major focus of concern was the ways in which the online delivery mode had constrained the coverage of course material: *"[during COVID-19 ET] we were probably covering 10-15% of what I expected to cover, because of discussions or because we went into some tangent. What we prepared was not fully delivered."*
- **language barriers:** a range of views was expressed about the impact of ET on students learning in their non-native language. Some interviewees raised concerns that students who *"have language barriers probably struggled the most with the online [learning]"*. They suggested that, without *"the discursive nature of working face-to-face, giving them the material and being able to talk through it first"*, many 'international' students struggled to engage in synchronous interactions with peers and instructors. Issues were noted to be particularly acute during *"project meetings with clients"* and internship experiences. Other interviewees, however, suggested that the online format offered new opportunities for this group of students to benefit from real-time translations or interpretations of the activities in their native language. Examples offered included: (i) *"live captioning in any language when you present in Office 365"*; and (ii) student peer interaction *"in their own language by text on WhatsApp or Discord"* alongside synchronous sessions to clarify the focus, structure and expectations of the session.
- **remote internships:** mixed views were also expressed on the value and impact of internships delivered online. For some interviewees, such authentic work-based experiences where you are *"walking through the corridors and jumping into the offices and talking to people, asking questions… [is] how an engineer works"*. Replacing such physical experiences with a virtual internship where you are *"sitting at home"* was suggested by some to be *"really damaging the development of the engineers of the future"*. Other interviewees, however, suggested that one crucial feature of internships is the way they expose students, often for the first time, to *"uncertainty, and things not going as you planned"*. As a result, they suggested that, as part of online internships delivered during ET, *"students will have learnt a terrific lot in terms of how to adapt and prioritise and seeing [how they can bring] value"* in a changing and uncertain context.

4. Emerging practices and cultures

Chapter summary:

This Chapter outlines six changes in engineering education reported to have emerged during ET.

Three relate to emerging pedagogical practices:

Section 4.1. Engagement with active learning: beyond the existing educational 'pioneers'.

Section 4.2. Remote hands-on learning: in place of on-campus labs and workshop activities.

Section 4.3. Assessment practices: that balance academic integrity with student wellbeing.

Three relate to emerging cultures and communities:

Section 4.4. External connectivity: with external stakeholders, as well as regional/global peers.

Section 4.5. Attitudes to teachers and teaching: including to education experts and team teaching.

Section 4.6. Faculty-student connectivity: by forming closer, less hierarchical relationships.

These practices and cultures emerged under the backdrop of the challenges outlined in Chapter 3. They also prefigure practices and cultures in engineering education that were anticipated to define the future of the sector, as explored in more depth in Chapters 6 and 7.

4.1. Engagement with active learning

When asked to describe the educational practices and priorities that emerged during ET, interviewees consistently pointed to a widespread adoption of active and blended learning.

As highlighted in the feedback and case studies throughout this report, ET was an unprecedented time for innovation and change in engineering education worldwide. While noting the acute difficulties of *"being aspirational when operating in 'survival' mode"*, interviewees also spoke about the opportunities afforded by ET for educational experimentation and innovation. Some suggested that, because the need for change was externally imposed and unavoidable, they were freed from many of the anxieties often associated with piloting new educational ideas, such as, *"what if it doesn't work, what if the students hate it… what if they end up not learning the material as well as before"*.

The online pivot also de-coupled course design from the constraints of on-campus learning spaces, allowing instructors to embed a mixture of different pedagogies – peer learning, videos, quizzes, group projects, etc. – at different points in their courses without needing to consider whether they could secure the physical spaces to facilitate them. Interviewee feedback made clear that a subgroup of existing *"teaching and learning pioneers"* within each department were often at the forefront of many of the new ideas and innovations in online learning during ET. However, many went on to suggest that the most far-reaching pedagogical change triggered by the online pivot occurred not amongst these existing educational 'pioneers', but amongst departmental colleagues who had historically *"really been stuck in a traditional way of teaching"*.

The online pivot brought into focus the weaknesses of teacher-centred pedagogies amongst some in this 'non-pioneer' faculty group who quickly recognised that *"you cannot lecture for 45 minutes… sitting and talking into a screen for 45 minutes online is awful"*. Student engagement during transmissive online 'lectures' was often low, with many turning off web-cams or *"not bothering to watch the sessions at all"*. Students were also noted to be reluctant to ask questions verbally during synchronous 'lectures' because, in many cases, *"if they say something stupid, its recorded for posterity"*. In turn, instructors spoke of the: *"loneliness [of] talking to serried rows of little black squares [on a Zoom screen]… the entire performative and embodied aspect of teaching just vanished overnight… that whole nonverbal communication which sparks something in us as teachers, that was all gone"*.

The experience was one that prompted some faculty to *"rethink the whole organisation of learning"*. Change focused, in particular, in two areas: the first was *"to break up my lectures into pieces, into different activities"*; the second was *"to make my classes more interactive… and activate my students"*. Many faculty members spoke about how they *"took a big step back"* to reconsider the aims, structure and learning modes for their courses, often working for the first time with educational developers to embed active learning pedagogies. In the words of one, the experience of ET *"has helped us to sharpen our thoughts on why do we do what we do? Everything was reconsidered – can we do this in a different way? And what is the rule? What is the aim of the learning activity that we're doing?"*.

This shift in practice towards active and blended learning was noted to be particularly marked at the start of the 2020/21 academic year: *"by our second semester, we had a really sizeable chunk of people who were pre-recording their videos and were doing much more interactive things in class"*. As the academic year progress, some also pointed to the effects of a *"positive feedback loop"* where instructors were able to connect changes in their pedagogical approach to improvements in student engagement and learning. For example, as concerns grew about the impact of ET on student wellbeing, instructors pointed to the ways in which the active and collaborative elements of their courses *"became an anchor for students during a very difficult year"*. In addition, students' results in the 2020/21 end-of-year exams appeared to validate the benefits of a blended approach. In the words of one professor: *"the students performed better than expected in the exams… we expected that they'd do terribly because they had such a messed-up experience"*. Many attributed these often unexpectedly strong performances to the increased use of active learning and the ability for students to access and re-watch short videos and online quizzes as part of their revision.

While the shift towards active and blended learning in many engineering schools was unprecedented and pronounced, many interviewees sounded two notes of caution. Firstly, it only impacted a minority of faculty, albeit a significant minority; in most engineering schools, a larger number continued with a traditional teacher-centred approach throughout ET. Secondly, the active and blended experiences developed were *"created in the 'survival phase' of ET"* and their quality and impact were therefore noted to be *"of varying quality"*. Nonetheless, the change was consistently noted to be profound. In the words of one director of a university-wide teaching and learning unit:

> *"in the second semester of [ET], we discovered a lot of teachers, something like 25%, were doing something that they were calling 'flipped classroom'. Now, it may not have been our definition of flipped classroom, but they were definitely trying to do something with an interplay between video and interactivity… beforehand, we could have told you the names of the five people to talk to about flipped classrooms at [our university]. Now, suddenly, it was like a quarter of all courses".*

Interviewee feedback also suggested that many instructors were opting to retain blended and/or active learning components in their courses as they transitioned out of ET as they *"realised that doing a 90-minute lecture does not work in a physical setting either"*.

4.2. Remote hands-on learning

One major question facing engineering schools in the early weeks and months of ET was how to offer students hands-on learning experiences – such as laboratory sessions (labs) and design-build activities – that would previously have been delivered in dedicated on-campus workshops and maker-spaces. Described by one as the "*beating heart*" of undergraduate engineering education, interviewees repeatedly characterised these experiences as ones that *"light a fire in the students"*, help them integrate their learning from across the programme, and build their identity as engineers.

While some universities opted to abandon such experiences or postpone them until later semesters in the students' programme, most sought to establish meaningful alternatives to these on-campus, hands-on activities. The alternatives developed typically fell into one of three types, as discussed in turn below:

1. **modelling, simulation, or remote activities:** online tools that allow students to model/test digital prototypes, simulate hands-on experiences, or control physical lab devices remotely.
2. **at home hands-on activities:** physical experimentation and/or design-build activities that can be posted to or 'found by' students and used/constructed within their home or dorm room.
3. **replacement activities:** alternative activities designed to provide students with some of the same learning outcomes as the in-person hands-on experience.

4.2.1 Modelling, simulation, or remote activities

Feedback suggested that the alternatives to hands-on activities most often adopted by engineering schools were modelling, simulation or remote activities, as accessed via digital tools. These included:

- **digital twins:** virtual models that simulate the behaviour of a lab, circuit or system. For example, the Department of Electrical and Computer Engineering at Bucknell University in the US used the *Multisim*[19] tool to enable students to simulate circuit labs during ET.
- **remote labs:** physical labs, typically on-campus, that are remotely controlled or explored by students via online instrumentation. Some have been established as fully-automated facilities that students can access any time, while others require on-campus support from an instructor or operator. For example, during 2020/21, students studying the *Experimental Methods* course in the Department of Aerospace and Ocean Engineering at Virginia Tech were able to explore the sound generated by wind turbine blades by taking remote measurements from the on-campus Stability Wind Tunnel, supported by an on-site tunnel operator and researcher.
- **digital simulation and modelling:** development and testing of 'digital prototypes' using 3D modelling and simulation. Students were often asked to submit these models in place of physical protypes during design projects. In some cases, instructors used on-campus 3D printers to create physical prototypes from these models, which were then posted to students.

Many engineering schools had already invested in some or all of these technologies prior to ET. The challenges associated with their adoption therefore often centred on scaling-up their application from single courses to full student cohorts: *"the issue for us was computing capacity, when you have 300 students descend on a simulation tool all at the same time"*. Despite early technical difficulties, interviewees pointed to several important benefits offered by these tools, which they anticipated would lead to *"lasting change"* to practices in engineering education, beyond ET.

[19] Multisim: https://www.ni.com/en-gb/shop/software/products/multisim.html

For example, the *"24 hour a day"* access offered by remote or simulated labs was noted to offer students both flexibility in their learning and new opportunities to *"try things out on a simulated version... make your mistakes, so that when you go in the [physical] lab, you're familiar and have a better sense of where to direct your time"*. In addition, the emphasis on digital modelling and prototyping during ET was often noted to yield *"more innovative solutions"* as students dedicated more time to reflect upon and iteratively improve their ideas, instead of *"jumping straight into workshop prototyping"*.

4.2.2 **At home hands-on activities**

Many engineering courses also offered activities to enable remote physical hands-on learning, typically undertaken in students' homes or dorm-rooms during ET. One of two approaches were typically taken:

1. **kit-of-parts:** a pre-designed kit of often relatively simple materials and tools that were shipped out to individual students to allow them to conduct experiments or engage in design-build exercises remotely. It was estimated that, in the Mechanical Engineering department at MIT, kits were sent out to students in 16 separate courses during the 2020/21 academic year. One example is Massachusetts Institute of Technology's (MIT's) 2.007 course, as outlined in Box 5.
2. **'found objects':** students developed physical experiments, devices or protypes using only the 'found objects' within their home or local area. One example from the 2020/21 academic year is from the *Thermodynamics* course at Olin College, where students were asked to use a mobile phone and objects from their homes to construct a device to measure temperature.

These 'at-home' hands-on projects were often associated with high levels of student engagement. While many interviewees pointed to ways that such activities could support engineering learning in the future, however, they also pointed to three factors that would hold back their wider adoption:

- **high cost:** the cost per unit for assembling and shipping kits to students was noted to be prohibitively high for many institutions;
- **limitation on students' design options:** in the words of one interviewee, *"a key constraint of having a fixed kit is that it reduces the possible solution space"* for students;
- **individually-focused:** at-home projects limit the scope for collaboration and team-working. One exception, where at-home kits were used as part of group projects, is given in Box 3.

4.2.3 **Replacement activities:**

The third approach adopted during ET was to replace on-campus, hands-on activities with alternative experiences that meet the same intended learning outcomes. Some involved live or pre-recorded demonstrations of lab experiments which were often noted to *"disconnect students from the doing, to passively watching"*. Others, however, developed replacement activities that, while not hands-on, offered students an exploratory, active, and engaging learning experience. In a surprising number of cases, the exploration focused on the analysis of real-world data sets. One example was the *Physics Junior Lab* at MIT: during ET, when they were unable to access the physical lab, students were instead given access to data and asked to replicate pivotal recent discoveries in experimental physics. So, as one interviewee explained, students were *"given data from the Large Hadron Collider, data that had been used to discover the Higgs boson, and they had MIT juniors repeating that discovery: they got the raw data, they learned how to analyse it, and they discovered the Higgs boson!"*. In a second example, as part of a *Data Science* course at Ahmedabad University in India, rather than *"going into the field and collecting data"* to evaluate water quality and resources in a local community, students were given access to regional public health data and asked to *"analyse the spread of COVID"*.

Box 5: **Design and Manufacturing I, MIT, US**

Theme highlighted: **Kit-of-parts to support at home hands-on learning**

Design and Manufacturing I (referred to as 2.007[20]) is an iconic course that exemplifies MIT's apprenticeship model of education, where instructors, in the words of the course co-lead, Professor Amos Winter, *"are teaching by doing next to the student"*. The course culminates in a robotics competition where students each design and build a device to accomplish a specific (and often whimsical) task based around a different theme each year. 2.007 seeks to build students' confidence and competence in the hands-on construction of their robots, as well as offer an authentic context to experience mechanical engineering principles in action, such as friction and compliance. Working in a machine shop, students are given 'physical homework' during the first half of the semester, where they are guided step-by-step through the construction of a simple autonomous robot (named 'Mini-me') that meets some of the competition criteria. During the final five weeks of 2.007, students design and build their own machine. At the semester close, the capabilities of each robot are tested on a custom-made 'game board', reflecting that year's theme, in a major showcase event designed to foster excitement, camaraderie and community across the student cohort.

2021 Home Alone 'game board' sent to students within their kits

The online pivot to ET came mid-way through the 2020 delivery of 2.007. With no time to prepare, students were forced to abandon their robots under construction in the machine shop and 'complete' them through the production of CAD drawings online. Soon after, it was decided that the 2021 course would be a fully remote activity, where robots would be constructed from home by *"turning students' dorm rooms into a workshop"*. A particular priority was to ensure that all students – regardless of their prior hands-on experience, physical location or home environment – could participate equally and fully in this remote course. Over the six months that followed, the course co-leads worked with a group of students and a teaching assistant to iteratively design, test and construct an adaptable kit of materials that students could use to build their robots at home.

The fully remote 2.007 was launched in February 2021. Each of the 130 enrolled students was sent a kit comprising materials, a workbench, tools and a 3D 'game board' on which their robot would be tested. The competition theme was based around the 1990 movie *Home Alone*, and students were asked to design a robot that could evade the various 'booby traps' devised by the lead character to repel burglars; the 'game board' was modelled on the house in the movie, with many of the booby traps in place. Building students' confidence and competence with using their kits was a major priority. During the early weeks of the semester, as students explored their kits and built the simple 'Mini-me' robot, instructors demonstrated the use of each of the tools provided in the kit. Instructors used a range of cameras at home to *"give students that hands-on type feeling even in the remote environment"*, allowing them to show the tools and materials from different camera angles during the demonstrations. Machine shop staff were also on-call by Zoom during the day to respond to student questions.

As 2.007 returned to the MIT campus in February 2022, one key element from the remote iteration of the course has been retained: while the final robots will be built in the on-campus machine shop, students will be sent a mini-kit of tools and materials to mock-up and modify their prototypes at home. As Amos noted, *"we found that having the ability to do work at home and practice with their robot improved the students' performance and learning in the class"*.

[20] Design and Manufacturing I, 2.007: http://me-2007.mit.edu

4.3. **Assessment practices**

Interviewee feedback made clear that – for instructors, educational designers and managers alike – assessment *"was one of the hardest things we had to grapple with during COVID… it was on our minds constantly"*. As one interviewee commented:

> *"I think the biggest challenge… [was] how we could modify assessment to a way that was still academically robust, but was fair for students".*

For many, the online pivot came less than two months before end-of-year or end-of-course assessments that had been planned predominantly around in-person invigilated, written exams. With little time for students or instructors to prepare, many engineering schools and universities took to the decision to scale-back and simplify these assessments. A particular focus was to reduce both the burden placed on students and the emphasis given to high-stakes assessments: *"you don't want a winner takes all environment when you're living in a pandemic"*. For example, many universities moved to a 'pass/no record' grading system, such that students either passed the class or receive no record of having taken it.

As they moved beyond the early months of ET, instructors started to look more critically at how to design and deliver effective online assessment systems. Their feedback suggested that four factors played a central role in shaping the assessment approaches they ultimately adopted:

- **instructor's time:** the capacity of instructors, at a time of unparalleled uncertainty and stress for most, to deviate significantly from simply *"transferring their written exam into the online space" while attentive to the risk of "that wake-you-in-the-middle-of-the-night terror of missing a mistake on your exam questions"* that goes unnoticed until students take the assessment.
- **students' digital access:** mindful of the inequality of students' digital access, and the unreliability of internet connectivity for many, interviewees pointed to the importance of offering flexibility in how and when students access online assessment and avoid, *"this 'rigid, absolutely no exceptions to the rule' kind of approach"* that works against equality of access.
- **academic integrity:** concerns about widespread 'cheating' in online assessments was a major topic of feedback, with many pointing to clear indicators of academic misconduct during the period of ET, such as test answers being published online or *"average marks going up-and-up"* over the course of a 24-hour open exam.
- **student wellbeing:** interviewees raised repeated concerns about the impact of high-stakes assessment on student mental well-being during ET, with *"invasive [online] proctored exams having a real cost on students' mental health"*.

Interview feedback pointed to an ongoing tension between these four factors. As ET progressed, many described a continuous monitoring and adjustment of assessment systems as they were seen to place excessive or insufficient weight on one or more of these concerns. The tension between academic integrity and student wellbeing was particularly acute, with interviewees often describing conflicts between instructors, programme managers and leaders at their institutions as they argued for different positions on the spectrum between the extremes of *"we must prevent academic misconduct at all costs"* at one end, and *"let's not overburden the students to prevent one or two from cheating"* at the other.

Despite these conflicts and constraints, many interviewees characterised ET as an unprecedented time of innovation and experimentation in assessment, with instructors increasingly looking beyond the traditional written exam. They pointed to examples of systemic change to assessment systems at all levels.

Some of this was undertaken at a **programme-wide or institutional** level, such as the requirement for all online classes to embed formative 'quizzes' at the Ecole Centrale Casablanca in Morocco, or, in 2020, the replacement of all first-year exams at UCL in the UK with a single integrated assessment that was specific to the students' programme of study.

Other changes have been implemented at an **individual course** level. Interviewee feedback suggested that a significant minority of instructors took the opportunity of the online pivot to fundamentally re-evaluate how and why they assess their students. As explored further in Section 6.3, interviewee feedback suggested that three forms of assessment proved particularly effective in the online mode. The first was the use of oral online exams, where students were given the opportunity to demonstrate and discuss their learning directly with instructors. The second was 'tokenised' or 'specification' grading, which offers continuous pass-fail assessments that are linked to key course learning outcomes. The third was 'synoptic' assessment, a single piece of assessment that asks students to integrate their learning from across multiple courses or even across their programme.

Whatever approach was taken, it was clear that almost every piece of assessment delivered in engineering programmes was the product of fundamental change during those early months of ET, be that to transfer existing assessment systems online or to fundamentally reform the form and focus of assessment. As one engineering leader noted, *"more changed in that 10 weeks [in preparation for the 2020 exam period] than had changed in 10 years. These utterly immovable regulations just got swept aside, these things that couldn't possibly work and couldn't possibly happen, got cast asunder as necessity just took over"*. As explored in Section 6.3, these experiences went on to catalyse a major community-wide debate on the purpose and role of assessment in engineering. In the words of one associate professor:

> *"quite a lot of us were saying, 'well, maybe the problem is not the students or the online format but the type of exam. Is it really what we want? You're just testing the student's ability to remember something that you've told them. Is that really a competency in the 21st century?... What is the purpose of assessment?'... I think it's really created a new type of dialogue that was really important – and still is".*

4.4. **External connectivity**

For most engineering faculty, ET imposed extended periods of physical isolation from colleagues and barred conference travel to meet with members of global peer communities. It is perhaps surprising therefore to note that over half of interviewees characterised this period as a time when they advanced their global connectivity in engineering education and/or fostered new communities of support outside of their home institution. Three dimensions of this strengthened global connectivity were repeatedly highlighted, as outlined below.

The **first** was connecting students with external stakeholders. Online learning was noted to offer *"new opportunities that we didn't have before to pull in experts from anywhere in the world"* to support and advance student learning. For example, some – particularly those based outside Europe and North America – spoke of how the online environment allowed them to secure *"a lot of very good passionate, ingenious experts coming in to talk to the students because now we don't have to pay for that airplane ticket"*. In addition to introducing world-leading subject-matter experts as guest speakers, the online environment was also noted to offer much greater flexibility for external partners to engage with student groups as mentors and advisors at multiple stages of group projects, rather than just *"coming in at the end as judges"*. Feedback suggested that alumni played a particularly prominent role in offering online mentorship and group project guidance during ET. Many also pointed to new opportunities that opened up during this time for students to engage in 'global projects' that *"connect students across countries and exposes them to different cultures and ways of thinking"*.

The **second** dimension of the new external connectivity was building communities of support with regional peers. ET was reported to have helped to foster new collaborations and support networks across regional peer institutions, often bridging those that *"compete for the same student [intake] pool"*. Several interviewees noted that, on the announcement of the online pivot, regional peer institutions *"opened up [remote] training workshops in active online learning"* that often brought together regional faculty from across disciplines. Several examples were also cited of engineering schools and institutions *"giving other students access to our classes"* and sharing facilities such as remote labs that were not available at other institutions. Engineering leaders also spoke about strengthening their connectivity to counterparts at peer institutions to share *"woes and strategies"*, to better understand how others are *"interpreting the rules that govern us"* and, in many cases, devise and agree common solutions to overcome shared constraints such as data protection regulations or accreditation requirements. Examples included weekly meetings between the executive boards of national specialist engineering and technology universities, and a new *WhatsApp* group that brought together engineering vice deans for education across the UK.

The **third** was strengthening global networks in engineering education. Around a quarter of interviewees reported that *"my network [in engineering education] has broadened enormously during the pandemic"*. They pointed to the *"comfort and help [of] talking to other people who understand*" the challenges of *"putting meaningful learning experiences together for our students"* in an online platform. For many, the online pivot of global conversations, collaborations and conferences in engineering education also facilitated greater inclusion of *"a much more diverse set of participants and people who wouldn't stand a chance to participate otherwise"*. Many noted that global travel for conferences *"has always been extraordinarily difficult for some of us"*. They went on to suggest that the online format had *"made it so much easier for people with families, or for people who have mobility or visual disabilities"* as well as those without access to travel funding to participate in these global conversations. Interviewee feedback also made clear that a significant number of regional or global engineering education groups took intentional steps to broaden membership and strengthen community during ET. Many pointed to the SEFI *Special Interest Group (SIG) for Ethics*[21] as one example, that deliberately scheduled online events to maximise participation across multiple time zones and actively engaged speakers and participants from regions that *"had not historically been involved with our conversations around ethics"*. As one of the Ethics SIG group members went on to note:

> *"once you put people together and build the community, actually networks start to happen on their own… there's a bunch of projects which are ongoing now which probably wouldn't have happened pre-pandemic".*

It is interesting to note that, while interviews pointed to a widespread sharing of advice and strategies to navigate the online pivot and ET, their feedback also suggested that they had limited visibility of *"what is actually happening"* in practice outside their own courses at their university. As one interviewee noted, *"it wasn't a time of great mobility of ideas. Most people are trying like hell to get their home organisations up and running in the new environment… Many of us don't even know what's going on [at a course level] at our own institutions"*.

[21] SEFI SIG for Ethics: https://www.sefi.be/activities/special-interest-groups/ethics-in-engineering-education/

4.5. **Attitudes to teachers and teaching**

Interviewees repeatedly referenced the personal commitment of faculty across their institutions to their quality of teaching and the learning experience of their students. Nonetheless, it was also noted that education had long taken a back-seat to research performance in university budget allocation models, academic promotion prospects and faculty *"conversations in the tea-room"*.

When reflecting on the positive impacts of ET, many interviewees pointed to a step change in this culture and in the way teachers and teaching were viewed at their institution. Many were clearly struck by the extent to which *"teaching suddenly became the top priority as we mobilised for the pandemic"*, with some commenting that *"I have never seen that at [my university] before"*. While the practicalities of the online pivot for university research were typically managed locally, by individual research groups or centres, supporting students and delivering ET often became the explicit and primary focus of university leaders at all levels of the institutional hierarchy.

This re-prioritisation was also apparent in the workload of faculty, with most noting they had invested *"colossal amounts of time and care"* in redesigning their engineering courses and activities for online delivery. It was also suggested that the experience of ET had brokered new faculty connectivity and communities of peer support in teaching and learning. Many also pointed to a breaking-down of traditional departmental hierarchies and greater willingness to share ideas, provide assistance and *"learn from each other's approaches… with everyone listened to, no matter of rank"*. Feedback suggested that this shift in culture played out in two highly visible ways, as outlined below.

The **first cultural change** was the increased visibility and status of *"the teaching experts in our university"*, a group whose activities had often hitherto taken place *"in the background"* of departmental activity. Feedback suggested that many education-focused academics and educational designers *"stepped up to the plate"* during ET to take on new leadership positions in establishing support systems for students and re-designing the curriculum for online delivery. Many also quickly assumed roles as informal mentors and *"focal points for development and support of their research-oriented colleagues"*. Interviewees went on to suggest that the experience of ET had *"given people who were teaching-focused a stronger voice"* and helped to both increase their visibility and build a widespread appreciation of the contribution that they make to teaching and learning in engineering.

The **second change** noted was *"a greater willingness to co-teach"* amongst faculty. One driver was the practical difficulties faced when preparing for and managing online learning: *"if you are planning to do a lot of interaction in online classes … you need someone answering questions one-to-one, you need someone else running the class, you need someone in the breakout rooms, you cannot do that alone"*. The shift was also noted to be influenced by *"the desire for people to socialise"* and take on unfamiliar technologies or pedagogies as part of a collaborative and supportive team rather than *"making all of these decisions by yourself, as a lone person"*. Box 6 provides an example of a teaching team approach that emerged during ET from Universiti Teknologi Malaysia (UTM) in Malaysia. One striking feature of the teaching teams established during ET was the prominence of UGTAs. Many noted that, during ET, the role of UGTAs had often elevated from *"doing grading or other administrative tasks"* to one of student mentorship, representing student concerns and experiences to faculty, and (in some cases) redesigning activities for more effective online delivery. For example, UGTAs played a major role in co-creating the online pivot of the *Engineering Challenges* core first-year course at PUC in Chile, as outlined in the case study on the CEEDA website[4]. Amongst other activities, the UGTAs designed and delivered week-long workshops to build students' skills in areas such as 3D modelling and online presentation skills.

Box 6: **Introduction to Engineering, UTM, Malaysia**

Theme highlighted: **Team teaching**

The *Introduction to Engineering* course is designed to introduce first-year Chemical Engineering students at the UTM to the role of engineers in society and to build their motivation for the four-year degree programme. The course director, Professor Khairiyah Mohd Yusof, coined the term 'cooperative problem-based learning' to describe the pedagogical approach taken by the course, which calls on student teams to tackle a regional sustainability challenge by working through a series of discrete problem-based experiences, each of increasing complexity. For example, the theme for the 2019 course had been 'love our river': working in collaboration with the local city council, students gathered and analysed data on the water quality in the river that passes through the UTM campus.

Following the pivot of the UTM Chemical Engineering programme to fully online delivery in March 2020, several challenges soon became apparent. This included concerns about student motivation and mental health, as well as their capacity to meet course learning outcomes, collaborate effectively with teammates, and regulate their workload when physically isolated from peers. In response, three major adaptions were made to the course, as summarised below, the first of which involves team teaching.

The **first adaption** was to co-teach: to combine the project taken in *Introduction to Engineering* with the project taken in another first year course, *Introduction to Computer Programming*. Merging these two projects offered several benefits. It allowed students to integrate learning across two previously separate courses; it offered more curricular time for team-mates to engage and work together; and it provided scope for more student support from the larger teaching team. Responding to the boom in online shopping precipitated by the lockdown in Malaysia, this integrated project focused on consumerism. Teams tackled the project in three phases: the first explored the topic of sustainability; the second asked students to audit the carbon footprint of their households; and the third was to develop a computer programme to calculate a user's carbon footprint and offer advice on lifestyle changes that could reduce their contribution to carbon emissions.

The **second adaption** was to embed goal-setting as part of students' metacognitive skills development, helping them to self-regulate their learning. Using the work-flow management app *Taskade*[22], students were asked to create a personal learning journal that was built step-by-step by identifying the learning goals and a plan of action for each class. As the course director explained, *"students were guided to reflect on their learning process to help them self-assess their thoughts, feelings, and actions to help them improve and internalise what they have learned"*.

The **third adaption** was to foster empathy within the project teams. In the words of the course director, "I wanted to explicitly include empathy to help the students develop a more caring attitude, to listen to others and to support one another… this is especially important for their mental health and emotional well-being when everyone was feeling isolated". At the close of each of the three project phases, students provided feedback on the needs and opportunities for peer support across their team. As the course director explained, "students were asked to write down the difficulties they were facing and the assistance needed, and to also write down what they perceive the difficulties their team-mates were facing and how they can help. The feedback forms were then given back to the teams and discussed during class time to see how the team working can be improved and how the team members can support one another".

All three of the adaptions described above will be retained and embedded in the *Introduction to Engineering* course in the future, beyond the period of ET.

[22] Taskade: https://www.taskade.com

4.6. **Faculty-student connectivity**

A repeated topic of feedback from all interviewee groups was the ways in which the experience of ET had forged *"a new closeness"* between students and instructors. This shift was described by one instructor as moving from viewing students as *"an ID number with test scores... [where] I am teaching you, you are learning and I'm evaluating you"* to *"we're in this together and you are a whole person"*.

Interviewees pointed to several linked factors that contributed to this change. The **first** was the *"shared experience of the online pivot"*, of both navigating the difficulties of remote working and, in many cases, experiencing repeated national 'lockdowns' that left much of normal life curtailed. Simply put, students and instructors were struggling with many of the same challenges and uncertainties at the same time. As they were called to make rapid and fundamental change to well-established courses, instructors often noted that they were *"very upfront with the students that I was going to be making mistakes and getting things wrong"*. In many cases, instructors worked collaboratively with students to co-design and improve course elements that *"were just falling flat"* in an online setting, particularly those designed to foster active student engagement and collaborative learning. The **second** factor noted to have *"broken down some of the hierarchies"* between instructors and students during ET was the ways in which online video-conference interactions provided *"a window into people's lives"*. As one interviewee commented, *"there's certainly a weird intimacy about all this, you know, where you're Zooming into people's homes, you're seeing people's dogs and kids and... their lives"*. Through this experience, it was suggested that *"students gained a lot more insight that faculty are real people who are trying their best and actually want to create positive experiences"*. For example, one student noted that they perceived their professors as *"less intimidating, in some ways, because you have seen them in a personal space"*. In turn, instructors were also noted to have *"gained a lot more perspective on students' experiences"* and the diversity of challenges that many face when accessing their education. The **third** factor was the *"openness and honesty"* offered by some instructors as they worked to combat some of the acute challenges that students were facing, particularly those around mental well-being and isolation. Many of the interventions adopted by instructors – such as *"starting lectures 15 minutes early to talk to students about their day"* or asking students to explore some of the mental health challenges associated with online learning – were noted to be *"a two-way street"*. In order to build a trusting and open dialogue, they often involved instructors sharing their own day-to-day difficulties and mental health challenges in ways *"that started to make people feel like we're all living the same problems, we are all the same"*.

Instructors often noted that, as a result of one or more of these factors, their relationship with students had transitioned from a 'teacher' role to a 'mentor' role over the course of ET. This shift could be seen most starkly in the ways in which students used 'office hours' sessions. Rather than *"a handful of students waiting outside my door to ask a very specific academic question"* prior to ET, 'office hours' often switched to regular online sessions that students booked at their convenience and which they would often attend as part of a group for pastoral rather than academic reasons. Many instructors noted that they had *"really got to know each of the students"* during these sessions, which were often noted to foster *"a lot of comradery"* as well as mentorship.

Interviewees expressed mixed views about whether these closer, less hierarchical student-instructor relationships would continue beyond ET. Some suggested that the relationship was rooted in the shared experience of the pandemic and was therefore distinct to *"this very special group of students"*. Others, however, pointed to a permanent change in the ways in which they and their colleagues would interact with students in the future: *"in a more human-centred and open"* way.

5. Lessons learnt for online learning

Chapter summary:

This Chapter synthesises interviewee feedback on lessons learnt from ET and how they would approach online or blended learning in the future. Each section is structured around a key question:

Section 5.1. What works better online? interviewee feedback on the activities that were more effective when delivered online, as compared to face-to-face.

Section 5.2. What is problematic to deliver online? interviewee feedback on the activities they consistency struggled to deliver online.

Section 5.3. What advice would you give to others? the advice interviewees would offer to instructors preparing to deliver active and student-led engineering learning online.

These three sections draw on the responses given to three interrelated interview questions:

1. What elements of engineering learning (if any) do you feel benefitted from the shift online during emergency teaching?
2. Which elements of engineering learning have been particularly problematic to deliver online (if any) during emergency teaching? Were you aware of any effective strategies adopted to overcome these challenges?
3. What advice would you give to an instructor seeking to deliver engineering education activities fully or partially online in the future?

The common questions asked of all interviewees is given in full in Appendix A.

5.1. What works better online?

Drawing on their experience during ET, interviewees were asked to identify learning experiences that appeared to better support student learning and development when delivered online, as compared to face-to-face delivery. Several were consistently identified. Most were experiences adopted during ET which instructors subsequently plan to retain within their courses.

Some experiences related to the broader benefits of online or blended approaches – such as enhancing flexibility, improving access or advancing self-paced learning – as explored in Chapter 4.

Other experiences were discrete online activities or tools that were noted to offer particular benefit over the face-to-face equivalent. Five such activities were repeatedly highlighted, as outlined in Table 2. It is interesting to note that all these activities are ones which facilitate: (i) access to new communities of support, feedback and information; and/or (i) flexible ways for students to connect with their peers, their instructors, and/or the external community.

1	**in-class engagement via "*back-channel chat*":** many pointed to the benefits of text-based chat tools – such as the Zoom 'chat' feature – that operate in tandem with synchronous activities to enable students *to "ask questions, throw in ideas... [or have] really rich side conversations".* Such online tools were noted to offer a rapid insight into what students were thinking, experiencing and struggling with, in a way that was difficult to replicate face-to-face: *"Zoom chat was superb, it gave me a back-channel, a window into the immediate student engagement reaction. The signal that came was stronger than just seeing their faces, that was new information that I would not have had in the in-person environment".* It was suggested that the anonymous and open nature of many chat features often emboldened students to *"type questions into the chat questions that they wouldn't have raised their hands in class to ask".* In the words of one professor*: "we've just opened up from 20 to 25% who are willing to speak out loud to now 80 to 90% who are willing to either send a chat that everybody else can see or send a chat that only I can see. It opens up the discourse between professor and student in a way that you just aren't going to get in your [physical] classroom".*
2	**asynchronous support through Q&A forums:** ET saw a dramatic rise in the adoption of online forums – such as *Piazza*[23] – where students' questions are logged and answered by instructors, teaching assistants, and peers. In addition to offering rapid support and feedback outside scheduled classes, the ways in which *"multiple students interact with each question to craft a better answer"* to questions posed was noted to offer a rich environment for community-based learning. As one educational developer noted, *"it's not simply: student asks the question, teacher answers it, and the answer is there. There is an actual constructivist process of learning happening there".*
3	**flexible learning that is independent of location:** the capacity to transition rapidly between different pedagogies and immediately divide the student cohort into different 'breakout groups' was noted to be a major benefit of online learning*: "that flexibility to transition between the big group and the small group, without any time penalty, was a revelation for us".* With flexible on-campus learning spaces often at a premium, it was repeatedly noted *that "online means that you don't need to think about booking rooms, [or] about where student groups will be able to meet. When its online, it can just happen, whenever people are free, it can just happen".*
4	**connectivity with external specialists:** as noted in Section 4.4, ET offered a wealth of new opportunities to involve guest speakers or experts from across the world in supporting group projects or specialist topics through online video connection: *"it's so much easier to approach someone about doing something for half-an-hour on Zoom than travelling to [our campus] and staying in a hotel".* Online connections vastly reduced the time commitment required by the external expert and vastly reduced (often to zero) the university's financial outlay to secure them.
5	**flexible student-instructor connectivity:** interviewees suggested that students and instructors were able to connect for 'office hours' or other mentorship/support activities in *"a much more flexible and immediate way"* during ET due to the online tools adopted. Using tools such as *Calendly*[24], students were able to book such meetings at mutually convenient times without the need to travel onto campus. These *"quick Zoom chats"* were also often scheduled *"when the student needs the help, not a week later"*, helping to offer more targeted support. As one professor commented, *"it just seemed like a shorter distance in some way from the students to the supervisor".*

Table 2. Activities/elements identified as 'working better online' by interviewees

[23] Piazza: https://piazza.com
[24] Calendly: https://calendly.com

5.2. **What is problematic to deliver online?**

Interviewees were also asked to reflect upon on which elements of engineering education were most problematic to deliver online and which (if any) they would prioritise for face-to-face delivery.

Their feedback predominantly focused on the delivery of team-based projects, which were noted to be *"one of the most motivational aspects of learning"* that allow students to see *"the purpose and meaning"* of engineering. In particular, interviewees often pointed to **key stages** in the project-based learning (PjBL) or problem-based learning (PBL) process that proved particularly challenging to deliver online. Feedback suggested that the online environment was associated with a particular set of challenges to catalysing *"motivation, goodwill, momentum, readiness within the team"* at these critical stages that often went on to have enduring impacts on teams' performance and learning throughout the project: *"we now recognise that there are pockets, moments in the life of an engineering team that can make or break whether this team will be high-performance... this is about going from good to great"*.

In particular, as illustrated in Figure 1, most identified one or more of three key stages in this PjBL/PBL process as most problematic to deliver online:

1. **early interactions:** interactions during the early weeks of a project to foster team bonding, expectation setting, scoping, planning and reflection on the problem;
2. **mid-project team-working:** interventions to identify and resolve conflicts, as well as activities to support ideas generation and brainstorming;
3. **closing event:** 'expo' events to showcase students' ideas/outputs, celebrate their achievements, and build their external networks with employers and clients.

When asked to identify which one of these three stages (if any) they would prioritise for face-to-face delivery, interviewees typically pointed to the 'early interactions' stage, noting its importance for establishing connectivity and trust between team members and thus reducing risk for future team conflict. Indeed, most of the identified challenges were associated with human interactions and establishing connectivity in an online environment: *"the most difficult elements [to deliver online] would be the social, natural-feeling interaction in the teams, and the interaction between the teams"*.

The three sub-sections below discuss the three stages in turn, exploring the particular challenges faced when such activities are delivered online and the ways in which interviewees sought to overcome them.

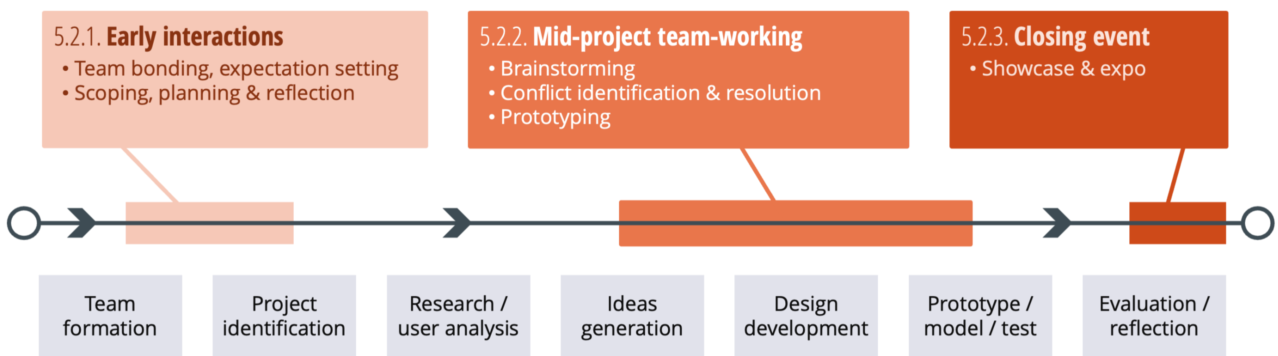

Figure 1. Stages in the PjBL or PBL process that would be prioritised for face-to-face delivery

5.2.1 **Early interactions**

Interviewees spoke at length about the transformative impact of an early face-to-face meeting on team interactions: *"from the moment students have met, everything works much better"*. For many, the experience of ET had laid bare the extent to which the establishment of *a "sense of belonging to a team"* and building trust between team-mates was *"a very physical experience"* that they had *"completely failed"* to replicate online. As one interviewee noted:

> *"nothing beats a face-to-face experience for just establishing some of those human connections… just coming to campus for three or four days, they meet, they talk together, they eat together… then when they go to their separate homes [and] jump on Zoom, they know who that person is on the other end".*

While team bonding was the challenge most associated with early project interactions, others were also consistently identified. Some challenges related to broader issues of student wellbeing and isolation (as explored in Section 3.2), such as students' capacity to build connectivity across the full cohort: *"there was much more focus on their own team – the learning from the other teams that were working on the challenge was way harder to facilitate"*. Other challenges included the capacity of students to build an understanding of, and excitement in, their project brief. The online environment often eliminated the capacity for students to physically explore the project context or meet stakeholders in these environments. As a result, it was noted that students were often unable to fully appreciate the project context and purpose: *"to get a hands-on feel for what's going on… something for their brains to picture when they're working on the project"*. Some interviewees went on to note that students also struggled to address *"intentionally ambiguous challenges, fuzzy problems"* when engaged fully online: *"part of the [challenge] is not only how to organise themselves but how to frame the problem in a way that it can be treatable. This messy sandbox is very difficult to replicate online. I think it's possible, but it's not as efficient"*.

Interviewees pointed to a range of remedial actions taken to address such challenges. Almost all involved activities to help students manage workloads (as described in 'Tip 4' in Chapter 5.3) or to foster trust and communication between team-mates (as described in 'Tip 5' in Chapter 5.3).

5.2.2 **Mid-project team working**

While an initial meeting was consistently identified as the single most crucial point for student teams to connect face-to-face, many interviewees also pointed to key activities at a project's mid-point that proved problematic to deliver online. The three repeatedly highlighted were: (i) hands-on prototyping; (ii) conflict identification and resolution; and (iii) brainstorming/ideas generation. The first of these components – prototyping – is discussed in Section 4.2. The second and third are discussed below.

Conflict identification and resolution: ET was noted to be a time when team conflicts and issues such as ghosting (where a team member does not engage at all with their team) became more prevalent. Often building on underlying problems with team connectivity (as outlined in Section 5.2.1), feedback pointed to two factors during the 'mid-project' stage that appeared to exacerbate team conflict.

The **first** was the tendency for teams engaged online to divide projects into discrete tasks to be undertaken independently by individual team members *"and then assemble everything together at the end"*. Due to this *"fragmentation of projects"*, students often struggled to *"create synergy in the project management"* leading to incoherence in the solutions developed. This approach was also associated with a dramatic reduction in ongoing cross-team communication or regular meetings. As a result, students were noted to have *"a difficult time 'sensing' each other and being open about the challenges they have"*, creating an environment in which conflicts were able to grow unnoticed.

The **second** issue repeatedly raised was that some of the strategies employed by instructors to identify and resolve conflict in a face-to-face setting were *"just ineffective"* in an online environment. For example, many spoke about the value of instructors *"reading the room"* when facilitating projects face-to-face as a mechanism to identify potential conflicts: *"I think the students call it 'the slow walk'. I peek from across the room and can kind of see what the dynamics are at a table. You don't get that kind of visibility on Zoom"*. Without these early indicators of potential problems, instructors often only became aware of conflicts after they had become deep-rooted and therefore more difficult to address. It was also suggested that ET had exposed the crucial role played by cross-cohort peer-to-peer advice in resolving conflict, an informal community of practice often rooted in the physical project space *"where they can see each other's work or they can overhear a conversation or talk to each other"*. Without such shared physical spaces where students can *"see others excelling and failing, and learning from that"*, many ongoing student concerns *"were directed at the teacher"* rather than being discussed and potentially resolved with cross-cohort peers during ET.

Some interviewees went on to note that, once team conflicts had become embedded within a team, it was often *"impossible"* to subsequently resolve them in an online environment: *"students will just turn off their cameras and you'll sit there and you can do nothing to facilitate conversations"*. Some described how, often for the first time in their career, they had disbanded teams and reallocated students to new groups due to intractable conflicts during ET. However, interviewees also pointed to a number of preventative strategies that they had employed to reduce the risk of such *"destructive"* conflicts emerging. These included: (i) establishing regular *"moments when students can reflect on how their interactions went that week… is anyone concerned or upset, to air it out"*; and (ii) encouraging students to build regular synchronous engagement into their team's daily or weekly schedule: *"keep Zoom open with peers throughout the day… if you need something, just unmute and ask, have a quick conversation and get back to what you are doing"*.

Ideas generation and brainstorming: the other 'mid-project team-working' component that was repeatedly identified as problematic to deliver online was 'ideas generation' or 'brainstorming'. The unstructured discursive and collaborative naturing of brainstorming, where *"you get that offhand comment, 'oh, that's a good idea' or 'what do you mean by that?' as you're doing it"* was noted by some to be one that *"simply does not work if you do it by screen"*. In the words of one dean:

> *"we don't seem to have good mechanisms for brainstorming, certainly not good mechanisms for the kind of conversations where things just spark off other comments and the speed at which that happens… That was one of the low points [of ET], I think it feels like that is very stilted".*

However, of the challenges associated with online team-based learning, brainstorming was the only one for which a core group of interviewees had identified a solution that had worked as well as – and, in some cases, better than – the face-to-face equivalent. This interviewee group pointed to their success using virtual whiteboarding tools such as *Miro*[25] and *Jamboard*[26] to support open collaboration and ideas development within and across project teams. These tools were used in a variety of ways: *"I've used it for students to post 'sticky notes' of ideas, to create mind-maps of their thinking, to sketch out solutions, to 'vote up' the ideas they like… to create a polished poster at the end of a project"*. More than simply replacing face-to-face experiences, several interviewees went on to suggest that virtual whiteboarding tools distinctive advantages over equivalent in-person experiences. For example, such tools were noted to provide a mechanism to break down team hierarchies:

[25] Miro: https://miro.com
[26] Google Jamboard: https://jamboard.google.com

> *"there's something collaborative about the Miro experience that is hard to replicate... There's some democracy to it ... everyone's just a cursor on that screen, and can grab a sticky note... and that maybe helps smooth over some of the dynamics that might happen if you're sitting around a table".*

These tools also provide a digital record of team ideas that can be saved, accessed and advanced at a later date: *"whenever you want to build some kind of memory as a team on how did you proceed from the first brainstorm to further [stages], you can follow your development in thinking in knowledge within the team"*. An example of the adoption of virtual whiteboard tools during ET is given in Box 7.

Box 7: **Graphic Communications, Arizona State University (ASU), US**

Theme highlighted: **Online brainstorming using virtual whiteboards**

For the past 10 years, Professor Christina Carrasquilla has taught two versions of her first-year *Graphic Communications* course, one in-person (delivered synchronously to almost 300 students enrolled at the Ira A. Fulton Schools of Engineering at ASU) and one online (delivered asynchronously to over 700 students worldwide enrolled in ASU Online[27]). Structured around the user-centred design process, the courses call upon students, in her words, *"to develop, practice, and see the value in the design process"*.

Soon after the introduction of ET in March 2020, Christina began to experiment with online tools to support collaborative problem-solving and ideation amongst what was termed the 'ASU Sync' cohort: the engineering students who pivoted fully online for the first time as a result of COVID-19 restrictions. She found two tools to be transformative: the collaborative whiteboard platforms *Miro*[25] and *Jamboard*[26]. While video conferencing platforms (such as Zoom) directed students' attention to the faces of their teammates, products like *Miro* and *Jamboard* directed attention to the ideas being generated and progressed by teammates, establishing a more dynamic and open environment for student creativity. As Christina noted, they allowed students to generate, in real time, visual maps of the influences on and evolution of the ideas under development:

> *"when we're using a shared digital solution for the class, it brings everyone into one focus... one of the most amazing things about that is you see what the other people are thinking, you can get a live update of the interaction not just the outcome".*

As ET progressed, the functionality of these tools improved considerably, as did students' capacity to navigate them. Indeed, rather than simply replicating a face-to-face experience, Christina became aware of the advantages offered by these online tools over and above in-person ideation. For example, students were able to review and comment upon ideas developed by peer teams without the disruption or time burden associated with physically relocating students. However, as Christina noted, the most significant benefit of these online tools was their capacity to connect the ASU Sync and the ASU Online students for the first time: *"we were able to put the students in the same space, even though they are separated physically by hemispheres in some cases"*.

Since ASU transitioned back to in-person education, from the spring of 2021, Christina has continued to use *Miro* and *Jamboard* to support students' team-working. She pointed, in particular, to the role that these tools can play in bridging the divide that often exists between 'online students' and 'in person students' when delivering in hybrid mode: *"that has always been the challenge [when in hybrid mode] – how do we make the online experience as good as the in-person experience... When you are all in a shared digital space, there is no hierarchy. It doesn't matter whether you are at home or in person, you are all working on the same digital product"*. Christina plans to continue to use *Miro* and *Jamboard* within her classes as a tool to facilitate students' collaboration and bring together mixed teams of in-person and ASU Online students.

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[27] ASU Online: https://asuonline.asu.edu

5.2.3 Closing event

In engineering schools and universities worldwide, flagship team-based projects often close with a celebratory event where teams solutions are presented to a 'judging panel' (for grading purposes) and showcased to an external audience. Many interviewees noted the pivotal role of these 'expo' events as *"a culmination of who the students are at the end of the project"*, providing a unique platform for:

- **fostering motivation and engagement:** *"knowing you're going to have to show your work to the whole world is a really powerful part of the teaching process because it changes the way you engage with the learning. Everybody must be up for the scrutiny of everyone who walks in the door"*;
- **network-building:** to build and strengthen relationships with project judges, employers, external partners, mentors, and peers;
- **celebration and self-reflection:** offering both *"a sense of celebration and completion"* as well as *"a discrete point from which to reflect on the experience"* and what has been learnt.

Interviewees went on to note the challenges faced in recreating these learning outcomes in an online environment, often reporting that *"the energy, the excitement just wasn't there"*. It was also suggested that tools such as Zoom *"support neatly-structured interactions"* rather than the sorts of serendipitous connectivity and *"that kind of organic, you look round the room and something catches you eye"* learning opportunities often fostered during an 'expo' event. In response to such challenges, some engineering schools and universities opted not to re-create all components of the 'expo' in a single online event, but instead devised one or more of the following discrete online activities, often delivered independently:

- **project grading:** in place of an 'elevator pitch' and/or poster presentation, graded deliverables were often switched to pre-recorded videos or stand-alone Zoom presentations. Some engineering schools and universities opted for alternative deliverables, however, such as the preparation and submission of a conference paper based on the project findings;
- **showcasing project outputs:** dedicated websites were often established to showcase team videos and presentations: *"so you can go to the website of the project and see the five-minute video of every single project.... that's a different communication artifact"*;
- **networking activities:** some engineering schools and universities adopted 'proximity chat' tools (that allow users to both interact as avatars in a virtual 'exhibition hall' and connect by video teleconferencing) such as *Gather*[28] and *SpatialChat*[29] to recreate *"that sense of walking around and seeing different projects"* during an 'expo'. Such tools both allowed users to access team's pre-prepared project products and interact with them synchronously.

Interviewees pointed to the need to re-calibrate their expectations of the role of expos when delivered online. As well as reflecting on what is lost by pivoting such experiences online, some also spoke about the benefits. So, for example, the capacity to invite students' extended family to an online event, or the accessibility of showcasing *"a permanent product, as a sort of online portfolio for students"* were consistently noted as clear advantages of online events. However, almost all went on to suggest that their preference would be to return to the face-to-face 'expo' at the earliest opportunity: *"there was a lot of really good stuff at the exhibition this year, but I didn't enjoy it … it didn't feel the same for the students, it didn't feel the same for our faculty… as human beings, we want to be able to connect with people"*.

[28] Gather: https://www.gather.town
[29] SpatialChat: https://spatial.chat

5.3. What advice would you give to others?

Interviewees were asked, based on their experience during and prior to ET, what advice they would give to other instructors preparing to deliver engineering learning online. The advice offered has been combined with other strategies and practices described by interviewees that were adopted in response to the challenges and opportunities presented by ET. Taken together, seven key pieces of advice for instructors emerged. These 'tips' can be divided into two broad categories, as summarised below:

Instructor-facing advice relating to course preparation and management:

- **Tip 1. Collaborate and experiment:** build a network of support via a teaching team and, in collaboration with students, experiment with different educational approaches.
- **Tip 2. Think through what you want the students to do:** during the course design stage, establish a clear focus and set of goals for both synchronous and asynchronous activities.
- **Tip 3. Provide a range of mechanisms for support and feedback:** ensure that students can access a variety of mechanisms to receive support and flag up problems or concerns.

Student-facing advice relating to course delivery and interactions with students:

- **Tip 4. Clarify expectations and foster self-regulated learning:** embed mechanisms that help students to understand course expectations and manage their workload.
- **Tip 5. Foster trusting relationships between students:** embed tools and activities to build empathy and connectivity between students.
- **Tip 6. Support wellbeing and provide a human connection:** integrate activities that offer students regular, personalised interaction and support.
- **Tip 7. Be upfront with students about what is going to be difficult:** highlight the challenges associated with online learning as well as effective strategies used to remedy them.

These seven 'tips' are explored in turn below. Short case studies are included alongside three of the 'tips' to illustrate how some of the practices described might be delivered in practice.

One striking element of the advice offered by interviewees was the prominence given to supporting mental health, of both instructors and students. Indeed, the first three 'student-facing' tips link directly to the three student mental health challenges identified in Section 3.2, describing in turn strategies to help students to manage their workloads (Section 3.2.1); build connectivity and empathy (Section 3.2.2), and support wellbeing and human connection (Section 3.2.3).

It should be noted that the advice offered only relates to online education and does not include advice on the design and delivery of effective engineering teaching and learning more broadly.

Tip 1. Collaborate and experiment

A common piece of advice for instructors was to *"mentally brace yourself"* for the isolation they may experience when delivering courses online. As one programme leader commented, *"you can feel very isolated… with that dull silence that you think is coming back [from students learning online] that can be quite desperate, so you must look after yourself as well"*. At the same time, workloads associated with preparing for online courses were noted to be high: *"when you're doing it online, you've got a completely new set of demands for the quality of the teaching resources. Now you've got videos, you've got the quizzes, you've got interactive sessions, you've got dozens of things to think about"*.

Several strategies were recommended to address these mental and practical strains. Interviewees advised instructors new to online education to *"sit in on an online class [where the instructor]… has found ways to get around the difficulties that present themselves"*. They also advised to *"start small and experiment, let your perfectionism go… it's like learning to ride a bike, the first stuff is not going to be as good as you think… but keep going with it"*. It was also recommended that instructors should *"spread the load"*, both mentally and practically, through team teaching: *"the thing that I would recommend strongly to anyone is to… work with others, learn from others, share with others"*. Many pointed to the benefits of forming teaching teams with peer faculty, educational developers and UGTAs to support the preparation of course materials, manage synchronous sessions and offer flexible student support. Many advocated *"involving the students"* in ongoing experimentation and evolution in course design, while first ensuring *"that the degree of experimentation each year is transparent"*.

Tip 2. Think through what you want the students to do

A consistent piece of advice given for those taking a blended approach to online education was not to simply *"lift and shift and do the same things with a Zoom link that you would ask people in a physical room and expect it to work the same"*. Instead, interviewees advocated taking *"a step back and think what is fundamental that you're trying to achieve"*: to focus on the core learning outcomes for the course/session. In particular, it was advised that instructors should *"think through the synchronous and asynchronous elements separately… thinking clearly about the goals and structure"* for each.

When considering the design of **asynchronous** course elements, interviewees pointed to the value of combining a range of different experiences – *"don't make everything a video, make it a mix"*– where each of the *"snippets"* prepared can be brought together to form *"a repository that students can refer to as needed"* at a later date. Two other aspects of asynchronous course components were also advocated. The first was that they should offer *"clear rewards"* for students, with deliverables that *"feed back into synchronous sessions"* to maximise students' engagement. The second was to design asynchronous components in a way that offered students time to reflect on problems before solutions are provided: *"that time and space [offered during ET] to think about the concepts before they saw the solution, that was very important for learning"*.

The design of **synchronous** course elements was clearly a source of concern for many instructors – with much of the 'technical content' delivered asynchronously, they struggled to *"fill the time, other than doing problem sheets for two hours"*. Such concerns often centred on *"what should I, as a teacher, be doing?"* during synchronous sessions. Several interviewees went on to advise instructors to instead re-frame their focus on *"what you want the students to do, and what is the purpose of that?"*. This may include sharing ideas, reflecting on problems, or collaborating with peers.

Tip 3. Provide a range of mechanisms for support and feedback

The online pivot was noted to have stripped programmes of many existing informal opportunities used by instructors to identify students who were struggling, and for students to flag up concerns or questions. One major piece of advice given for the design of online courses was therefore to embed a variety of different platforms to provide student support and collect student feedback:

- **student support:** offering a range of mechanisms, both synchronous and asynchronous, by which students can receive help, support, and advice. In particular, some recommended offering different 'levels' of support, spanning (for example) feedback given to the full cohort about common mistakes made during an assignment, asynchronous online forums for students to ask questions, and to one-to-one mentorship and advice. One course that has introduced such a range of 'levels' of support, from ASU in the US, is explored in Box 8.
- **student feedback:** providing regular opportunities for students *to "let the [instructor] know when they are having problems or when things aren't working"*. Interviewees spoke about the importance of *"not letting problems fester"* when working online through embedding different mechanisms for students to report issues they are facing or make suggestions for course improvements, such as via weekly discussion sessions with UGTAs, anonymous forums, 'chat' functions during synchronous sessions, or private messages to instructors. Instructors' response to the issues/concerns raised should also be clearly communicated to students, be that to identify what remedial action has been taken to change/improve the course or to explain why remedial action was not possible/feasible.

Tip 4. Clarify expectations and foster self-regulated learning

As explored in Section 3.2.1, students often struggled to understand course expectations and manage workloads when learning online and physically dislocated from peers during ET. Advice offered to combat these challenges focused on *"structure and communication"* as outlined below:

- **articulate course expectations, structure and deliverables:** adapting course structure to *"break the work into chunks" as well as "walking students through the semester, step-by-step"*, explicitly highlighting key tasks and deliverables. For example, during ET, the Bell Program at Iron Range Engineering in the US, brought all students together for a 10-minute online morning meeting each day to *"engage them, pump them up"* and run through the structure, focus and expectations for the day to come. Interviewees also advocated making all course expectations (academic and professional) explicitly clear, and creating a single repository for students to access all course information and resources. Interviewees also noted that *"in terms of pacing and keeping students on track, it is important to have fixed points where students come together regularly in real time for live interaction"*.
- **foster self-regulated learning:** embedding mechanisms to help students manage both their workload and their time. Many advocated encouraging students to keep a personal learning journal where they can *"capture a sense of their progress [and] punctuate their journey… to stop and reflect on 'What have I learned in this week? What am I going to focus on next week?' Go back at the end of next week and say, 'Did I focus on that thing?'"* (an example of the use of a learning journal is given in Box 6).
- **coordinate interventions:** bringing instructors together to devise coordinated, programme-wide support plans for students who are struggling with their workload. For example, rather than *"expecting the student to figure it out, course by course"*, members of the first-year teaching team at Olin College come together to identify students who may be struggling and *"chart out a path to support them for the entire semester"* across all courses and activities.

Box 8: **Principles of Programming, Arizona State University (ASU), US**

Theme highlighted: **Offering different 'levels' of student support**

Historically, the first-year *Principles of Programming* course (CSE 110) at ASU) has been associated with low student retention. In recent years, two ASU engineering professors – Ryan Meuth and Phillip Miller – started exploring how adaptive learning[30] might be used to improve student engagement in this large-scale course, taken by around 3000 students each year. One hurdle they faced in taking an adaptive approach to the course was the sheer variety of different, but still correct, answers that a student might provide to a coding problem. As a result, as Ryan explained, *"we took a much more human-centric approach than the fully adaptive system"*, one which combines online resources with targeted student support delivered both online and in-person. This pilot version of CSE 110 was launched in September 2021 during ET.

Working in partnership with *zyBooks*[31], an 'interactive textbook' tool, the teaching team disaggregated the CSE 110 curriculum into a series of 178 discrete interactive asynchronous resources. All resources and course assessments are embedded in the *zyBooks* platform, including videos, an interactive textbook and web-based coding assignments, through which students are given real-time feedback. As Phillip commented, *"students get a lot of little feedback loops, so they're trying things out as they go"*.

In parallel with these resources, students are offered five 'levels' of support, as illustrated below.

The first two support levels are delivered online via *zyBoo*ks: **Level 1** is automated feedback on students' coding submissions; **Level 2** is a moderated discussion community[32] where students' questions are answered by peers and instructors. The next two support levels are delivered synchronously: **Level 3** is a weekly lab session; and **Level 4** is a daily 'drop-in' session providing opportunities for collaboration with peers and one-to-one support from a Teaching Assistant (TA). **Level 5** is one-to-one support from instructors, which can be instigated by the student (through attendance at 'office hours') or instigated by instructors (where they use data from the LMS to identify students who are investing time in a topic but not progressing). This instructor-led help may come in the form of a 'hint' emailed to the student, or through directing students to a face-to-face support session. As Ryan commented: *"because of the real time data, we can identify the students who are stuck right now and they might not reach out on their own… that is where instructors are spending their time, understanding where the students are and offering the support that that specific student needs"*.

Level 1	Level 2	Level 3	Level 4	Level 5
Automated feedback to assignments	InScribe community discussion board	Weekly 75-minute lab session with TA	Daily drop-in TA support session	One-to-one instructor support

The data captured on student progress also allows the teaching team to refine and adapt course materials in real-time. For example, data from the 2021 course suggested that students were struggling to differentiate a 'float data type' from a 'double data type'. Within days of this issue emerging, the teaching team were able to amend course materials related to this topic and saw an immediate improvement in student progress. As Ryan noted, *"it's a living course, and change is driven by real data and analysis rather than anecdotal evidence and a 'feeling' of how well it's going"*.

ASU is currently considering whether this approach could be scaled-up across the full cohort of 3000 CSE 110 students. At the same time, Ryan and Phillip are exploring ways to develop a fully-adaptive version of CSE 110 that can be accessed by larger groups of learners from outside ASU.

[30] In adaptive learning, an algorithm is used to tailor the feedback, support and resources given to each individual learner.

[31] zyBooks: https://www.zybooks.com

[32] InScribe: https://www.inscribeapp.com

Tip 5. Foster trusting relationships between students

One of the most significant challenges faced during ET was building trust and connectivity across the student cohort when learning remotely (as explored in Section 3.2.2). Advice repeatedly offered by interviewees to address this issue is summarised below:

- **embed online tools to foster cross-cohort connectivity:** adopting 'proximity chat' or other online tools that blend social and academic interaction to broker informal connections between students. For example, in the 2020/21 academic year, the first-year engineering programme at Purdue University used the 'proximity chat' tool *Gather*[28] *"to help students find their study groups… but also to give students back the thing that was really taken from them in this pandemic, that ability to just hang out"*. In a second example from MIT, as outlined in Box 9, a bespoke online tool was used to foster the exchange of help and advice between student teams.
- **build empathy:** embedding activities to foster empathy between team-mates and across the student cohort (as discussed further in Section 3.2.2). One example is the peer-feedback and self-reflection exercises embedded into the *Introduction to Engineering* course at UTM in Malaysia (Box 6). Others interviewees recommended keeping students in consistent groups to allow more time for these relationships to build across the semester or year.
- **establish social cohesion within teams:** encouraging teams to establish a "*common identity*" through identifying shared interests or ways to socialise outside their projects, such as via holding a *"common lunch together"* each day, holding weekly meetings where *"they only talk about social stuff"*, or identifying *"an online [computer] game that they can congregate around"*.

Box 9: **2020 Design Challenge 1, MIT, US**

Theme highlighted: **Building trust and connectivity across student teams**

Design Challenge One (DC1) is the first of five major team-based design challenges tackled by students during their first year of study on the System Design and Management (SDM) Master's course. A new cohort of second-year SDM students are engaged as Teaching Assistants (TAs) each year, and are encouraged to take a lead in evolving the DC1 experience. The group of TAs engaged in 2020 took the pivot to ET as an opportunity to rethink and redesign DC1 for delivery online to a physically-dislocated cohort. What emerged was an activity that utilised a new web platform to enable the distinctive features of the course: collaboration, peer-support and network building across the student cohort.

The 2020 DC1 built on a partnership with the regional city authority. Each student team was asked to develop *"a tangible solution"* to a major sociotechnical challenge facing the City of Cambridge, home to the MIT campus. The DC1 teams used a public-facing web platform to document the development of their projects in real time. This supported student learning and the wider collaborative ethos of DC1 in two ways. Firstly, it allowed internal and external stakeholders to gain insight into each team's progress and thinking, as well as the evolution of their projects. Secondly, inspired by crowdfunding platforms, it allocated a virtual currency to teams and other stakeholders which they were invited to spend through 'backing' other teams. These virtual coins could also be spent as tokens of thanks to a team or a stakeholder for help provided or to signal appreciation of the quality of the project.

All teams benefitted from the giving and receiving of these 'coins': in order for all teams to successfully complete the course, a threshold number of 'coins' had to be exchanged in total. Help might come in a variety of forms and included: connecting the team to an expert in regional homelessness; providing training for video editing; or checking foreign language translations on an app interface. This backer system provided a gateway for students to seek and give peer support and helped them to build networks and communities at a time of isolation for this physically-dislocated cohort.

Tip 6. Support wellbeing and provide a human connection

Interviewees noted the difficulties faced by students in maintaining mental wellbeing when learning online and isolated from peers, with many suffering from low motivation and anxiety (see Section 3.2.3). Advice consistently given to instructors to combat these issues is summarised below:

- **focus on the individual:** providing *"individualised attention in an environment where students feel like a number"*. Many therefore advocated *"using a students' name when you put a comment in the chat"* or *"taking the time to recognise a student, to meet with them personally, to remember their names, those kinds of things really go a long way"*.
- **humanise your interactions with students:** working to be *"more human in our classes, really listen to [students] and to make visible the fact that everyone is struggling with these challenges"*. Some suggested that *"asking normalising questions, like 'how do you think you're doing? How do you think everyone else is doing?'"* helping to reassure students that *"you're not isolated and alone and the only one feeling like this"*. Others spoke about how they were *"open with the students and admitted that I had my own struggles that I was experiencing with mental wellbeing… and sharing some things that worked for me"*.
- **offer flexibility and autonomy:** offering students flexibility and autonomy at a time when they had limited control over their environment or ways of learning. For example, during ET, students in the *Sustainability Education* course at Wageningen University in the Netherlands, were given complete flexibility over the form of the final deliverable for their course project, be it a song, a collage, a video, or something else entirely.
- **embed regular 'check-ins' with students:** being *"much more proactive in reaching out to students and checking they're okay"*, incorporating regular 'check-in' sessions at the beginning and/or end of classes to *"give more opportunities to voice when things are challenging"*. Many also encouraged students to *"send a quick private message that their classmates wouldn't see"* to alert instructors or supervisors to any difficulties faced.
- **build engagement and motivation for new students**: developing targeted activities for incoming first-year students to build their engagement and community connectivity before starting their studies. For example, following the online pivot in 2020, Ashesi University in Ghana developed the First Year Experience (FYE), a three-month preparatory experience to foster motivation and *"a sense of purpose"* amongst its incoming first-year students. Structured around an immersive team-project, the FYE aimed to contextualise students' undergraduate learning and demonstrate how their education could enable them to lead systemic and positive change across the African continent.
- **embed activities to foster wellbeing**: integrating targeted interventions within the timetable to foster student wellbeing. These ranged from one professor at the Korea Advanced Institute of Science and Technology who played music before the start of each online class, to the roll-out of an elective course on the *Science of Wellbeing* in the engineering school at the Pontifical Catholic University of Chile (as outlined in Box 14). Many also offered mindfulness activities, either as an optional drop-in session or embedded within scheduled classes.
- **engage UGTAs:** engaging UGTAs to help facilitate one-to-one peer support: *"my advice is to hire [UGTAs], trust them, and give them space… the students related to the [UGTAs] more as peers, opened up a lot more, were more willing to share where they were struggling… you can't underestimate how much that was needed"*.

Tip 7. Be upfront with students about what is going to be difficult

The final piece of advice repeatedly offered was *"to make clear to the students… what are the risks here, what are the potential problems that you have to be aware of when learning online"*, such as social isolation, difficulties managing workloads or the increased risk of team conflicts. Box 10 provides an example of where the challenges of learning in an online environment are explicitly addressed.

Two major benefits were associated with "being upfront" with students about the challenges and risks faced when learning online. The first was that students were less likely "to feel alone, like they are the only one who has failed" if they encounter such issues and may therefore be more inclined to seek help and support. The second was that students were more likely to appreciate the importance of activities designed to allay these risks or challenges and therefore engage more fully with them.

Box 10: **Engineering Statics, TU Delft, Netherlands**

Theme highlighted: **Being upfront with students about the challenges faced**

Statics is an introductory seven-week course taken by all 450 incoming Aeronautics first-year students at TU Delft. In both September 2020 and 2021, the student cohorts joining the course – and the university – were studying 100% online with no opportunities to connect face-to-face with peers.

In this online environment, the course co-lead, Professor Calvin Rans, took the decision to contextualise the course around a 'Mission to Mars' narrative where students would assume the role of *"an astronaut travelling to Mars for the first time".* The narrative was used to frame all technical problems that students tackled during the course. For example, the first scenario saw the astronaut touch down some distance away from the intended landing site on Mars, and students were asked to design a bridge to traverse a crevasse on the planet's surface using only the materials available in their spacecraft. The 'Mission to Mars' context was also used to expose and explore some of the challenges that students were likely to face during ET by drawing a parallel between the effect of long-term space-travel and the experience of remote learning. Four challenges common to both scenarios were explicitly addressed:

- **overcoming boredom:** storytelling and role-play were used to motivate and engage students, and help them to *"have fun with the backstory"* established through the space exploration context through, for example, creating a series of light-hearted animations about the characters[33].
- **loss of time perception:** targeted support was offered to help students foster a healthy work-life balance and establish schedules to manage their workloads. One focus was helping students to structure and manage their working time: each was given a weekly planner – designed as a 'flight data recorder' – where they could plan their work schedule and reflect on their study habits.
- **isolation and loneliness:** UGTAs were engaged to play a central role in fostering peer interaction and connecting students with an on-campus culture and lifestyle that they had yet to experience in person. For example, UGTAs recorded a weekly *"message from home"* video, to offer insight into their own experiences of and reflections on ET.
- **unexpected problems:** in the context of the unforeseen problems faced during historic space missions, students were offered regular opportunities to talk about the challenges they faced and provide feedback to instructors on elements of the course that could be improved.

Many of the reforms made to the *Statics* course during ET – including the blended format, self-reflection via the 'flight data recorder', and the 'Mission to Mars' backstory – have since been retained. All synchronous elements, however, including interactions with UGTAs, are now delivered face-to-face.

[33] Engineering in Space, YouTube video: https://www.youtube.com/watch?v=1_1jeiT6HoE

SECTION B.
BEYOND EMERGENCY TEACHING

Section B of the report focuses on the anticipated impact of ET and COVID-19 on the future state of the art in engineering education.

It explores interviewees' perspectives on:

- **New directions for the sector (Chapter 6):** new priorities, practices and cultures expected to be a feature of cutting-edge engineering programmes that were noted to have been triggered or enabled by the experience of COVID-19 and ET.
- **Acceleration of existing trends (Chapter 7):** the ways in which COVID-19 and ET were noted to have accelerated or validated the priorities, practices and cultures already under discussion or implementation in engineering programmes prior to 2020.
- **Concerns and risks for the future (Chapter 8):** the challenges and risks facing the global engineering education sector that were seen to stem from the experience of ET and COVID-19.

The themes highlighted in this Section are ones which act <u>in combination</u> with existing trends in global engineering education practice and challenges facing the sector prior to 2020, many of which are outlined in the 2018 MIT report[1]. These include trends towards multidisciplinary, experiential and project-based learning, as well as the challenges faced by large publicly-funded institutions in delivering such pedagogies at scale.

It should also be noted that the trends and priorities expected to emerge across the engineering education sector, as outlined in Chapters 6 and 7, are likely to relate to engineering programmes operating at the **cutting-edge** of global best practice.

Context for Section B: a sector in transition

Section B of the report summarises interviewees' perceptions, expectations and concerns for the engineering education sector as it transitions beyond ET. As they looked to the future, interviewees often spoke about how their short-term priority was to *"repair the damage done by COVID"* to on-campus cultures and communities: *"getting the energy back and the vibrance and the curiosity"*. Reflecting on the toll that COVID-19 and ET had taken on the mental wellbeing and academic progress of both students and instructors, they also spoke about the need to provide targeted support to these communities as they transitioned out of this period of exhaustion and uncertainty.

When considering the long-term impact of ET, most interviewees anticipated fundamental changes to priorities, practices and cultures across the sector, describing how the experience had *"rocked the foundations of our engineering education"*. In the words of one programme leader:

> *"we learned a bunch of new things [from ET] and we're going to do things differently as a result of this. There's no question in my mind, it's a game-changer".*

Taken together, their reflections on the sustained and positive influence of ET on best practices in engineering education pointed to two types of long-term impact, as outlined below.

The **first** was to precipitate new directions in engineering education, as described in **Chapter 6**. For many across the sector, the online pivot was noted to have catalysed far-reaching educational changes in engineering schools and universities that may have never emerged but for the systemic shock of ET. The experience had led many across the sector to *"ask big questions like 'what is a university for?' and 'what is the value [that] going to university adds?'"*. As one interviewee commented:

> *"there is a recognition of how the eruption of everything [during ET] also created a foundation for something new. I think where we're at now is... a process of going back to basics; what is the importance of education? What is the importance of meeting people?... There are some really fundamental questions that have been formed from this".*

This sense of a sector undergoing fundamental re-evaluation and self-reflection is seeded throughout Chapter 6, in questions ranging from *'how does the campus help to foster student identities, cultures, and communities?'* to *'what role should engineering schools play in supporting students' mental wellbeing?'*.

The **second** was an acceleration, validation and enhancement of changes in engineering education already in train prior to COVID-19, as described in **Chapter 7**. ET provided the opportunity for an at-scale 'stress test' of practices – such as blended learning, digitisation or flexible learning pathways – that have been under development in the sector for decades but which had often proved problematic or *"slow to roll-out"*. As a result, many root-and-branch reforms in engineering education are now seeing both an increase in their ambition and an acceleration in their timescales for change.

These two types of impact – opening up new directions and accelerating changes already in train – represent broad trends and the boundaries between them are not always clear-cut. It should also be noted that these positive developments will not be enabled sector-wide: interviewee feedback made clear that in many engineering schools and universities, their emergence will be held back by major barriers. Indeed, almost all interviewees spoke about key risks and challenges facing engineering education that had been precipitated or exacerbated by COVID-19 and ET. As outlined in **Chapter 8**, these included concerns about the stratification of the engineering education sector as a whole and about how the experience of ET risked promoting an approach to online learning that prioritises institutional income over student learning.

6. New directions for the sector

Chapter summary:

Interviewee feedback suggested that ET had catalysed new directions for the engineering education sector. Although often long advocated in the pedagogical research literature and appearing in pockets of good practice, such approaches were unlikely to have emerged or been embraced at scale across the engineering education community but for the destabilising impact of ET. Interviewees anticipated step-changes in best practices in engineering education in six major areas:

Section 6.1. Active and collaborative learning: wider adoption of these student-centred pedagogies.

Section 6.2. Team teaching: a marked shift in the adoption of teaching within diverse teams.

Section 6.3. Assessment practices: a more diverse and dynamic approach to assessment.

Section 6.4. Mindsets and wellbeing: a sharper focus on fostering mindsets and wellbeing.

Section 6.5. Flexible, collaborative learning spaces: new priorities for on-campus learning spaces.

Section 6.6. Co-produced educational strategies: the move towards evidence-informed educational decision-making that is co-produced with students, faculty and in-house pedagogical experts.

6.1. Active and collaborative learning

As they looked to the future, many interviewees anticipated a step-change in the acceptance and adoption of active and collaborative learning amongst faculty groups that may never have moved away from teacher-centred pedagogies but for their experiences during ET.

Prior to 2020, active and collaborative learning had become an increasing feature of many engineering programmes worldwide. The design and delivery of these student-centred experiences, however, often fell to a relatively small sub-set of the engineering academic community: a group described by one interviewee as the *"teaching enthusiasts"*. Their academic colleagues, in contrast, often remained unaffected by the introduction of these active and collaborative components, and continued to adopt the teacher-centred lecture-based approach that dominated the rest of the curriculum. As interviewee feedback made clear, despite the efforts of many in the engineering education community, the case for student-centred learning was not sufficiently compelling to convince those in the latter group – the 'traditional instructors' – to invest the time needed for such a pedagogical change prior to ET.

As explored in Section 4.1, ET laid bare the weaknesses of teacher-centred pedagogies – particularly with respect to student engagement and peer-to-peer connectivity – and catalysed a fundamental change to pedagogical practice amongst a significant minority of engineering instructors. It was a change that often came in two stages: the initial redesign of courses for online delivery and then, in the months that followed, the incorporation of active, collaborative and/or blended learning as concerns about student isolation, overwork and wellbeing grew. In contrast to historic educational reform efforts, engagement with these changes reached beyond existing 'teaching enthusiasts' to encompass many in the group of 'traditional instructors', often for the first time. This was a change that many suggested would not have been possible but for the destabilising effect of ET. Indeed, one lead of a teaching and learning unit simply noted that the experience of ET *"has opened people's eyes to different* *styles of teaching far more than 20 years of centres of learning and teaching have ever managed"*. Many interviewees reported that these changes went beyond classroom practice, and reflected a profound shift in attitudes to teaching and learning amongst key groups that had not historically engaged with pedagogical development. They went on to suggest that the experience of *"dipping a toe in the water of new ways of teaching"* prompted many instructors to confront fundamental questions – and challenge deep-rooted assumptions and beliefs – about the purpose and place of engineering education in the 21st century. In reflecting on the sustained impact of ET, one university leader noted:

> *"a big part of the value is just going to come from the fact that everyone has spent a much larger fraction of their time thinking about how do students learn, what do I want them to learn, what are my learning goals for my students, and how do I teach so as to achieve those goals? So people were forced to ask all those questions because they're teaching in a new way by a new medium. I think the fact that they have asked themselves those questions will yield benefits [for the future]".*

After up to two years of ET, these step-changes to pedagogical practices and cultures were noted to have become embedded for a significant minority of faculty. Interviewees therefore anticipated a wider adoption of active and collaborative learning, beyond isolated 'flag-ship' courses and existing 'teaching enthusiasts', to embed student-centred learning across wider swathes of the curriculum.

6.2. **Team teaching**

Interviewee feedback suggested that ET had also catalysed a major shift in attitudes towards team teaching – instructors working collaboratively with, for example, peers, educational developers and students in course design and delivery – and anticipated a marked increase in its adoption beyond ET.

As noted in Section 4.5, ET saw increasing numbers of instructors turn to team teaching as a mechanism to meet the wide-ranging demands of online and blended learning. As one reported:

> *"[ET has] made us rethink the way we're doing courses. So it is traditionally one lecturer who is doing the course… [but] when you see how you make a good online course, it's not a one-man show. It makes more sense to see that as a team, where you have some people who are experts in the field, you have some people who are very good at making animations, you have some people who are very good in explaining… and then you see [after returning to campus] that it is better as a group face-to-face too".*

In recognition of the benefits it affords to instructor flexibility and student support, it was anticipated that this collaborative teaching approach would be retained by many beyond ET. Interviewees anticipated too that this new generation of teaching teams would be marked out by their diversity of membership. ET was noted to be a time that prompted *"new conversations about teaching and learning"* across the academic community and brokered new connections between instructors and educational developers from across disciplines and backgrounds. The diversity of these new communities was often reflected in the composition of the teaching teams formed during this time, a trend that was expected to continue. A range of benefits of diverse teaching teams were noted, such as helping students to connect disparate curricular topics/disciplines, and increasing capacity to embed a range of pedagogies and learning experiences into courses. Building on the positive experiences during ET, UGTAs were also anticipated to play a pivotal role in this next generation of teaching teams, bringing with them unique insight into students' experiences, new perspectives on how to address challenges faced, and the capacity to deliver wide-ranging student support from within their peer group.

One example of the sustained impact of ET on the adoption of diverse teaching teams is given in Box 11 from Tec de Monterrey in Mexico.

Box 11: **Tec21, Tec de Monterrey, Mexico**

Theme highlighted: **Collaborative team teaching**

Tec de Monterrey is a private university spread over 26 campuses across Mexico. In 2019, the university launched Tec21[34], a new undergraduate curriculum grounded in challenge-based learning and framed around authentic industry or societal problems.

Tec21 is structured around five-week curricular cycles which comprise core 'courses' (related to each students' major discipline) and elective 'blocks' (that allow students to build specialist competencies in different fields, such as *nanotechnology*, or topics, such as *Immersion and Creative Experimentation*). Each block comprises two components: a set of fundamental 'modules' and an authentic team-based 'challenge'. The multidisciplinary teaching team that designs and delivers each block must ensure that the modules provide students with the knowledge, skills and mindsets needed to tackle the challenge. In addition, for each semester of study, Tec21 stipulates a set of 'core' competencies to be embedded in all blocks delivered during this period (such as *social intelligence* or *critical thinking*). The block's teaching team must ensure that, taken together, their modules and challenge meet these 'core' semester competencies. This university-wide, coordinated approach offers considerable flexibility for each student to follow a bespoke learning pathway that aligns with their interests while also ensuring that they all build a common set of core competencies over time. In other words, student choice in their selection of blocks does not come at the expense of the scaffolded development of their competencies.

Tec21 had been operational for less than a year when Tec de Monterrey pivoted online in March 2020. While these early months of the new curriculum had been successful in many ways, one limitation was apparent: students studying at Tec de Monterrey's smaller campuses were able to choose from a much smaller selection of blocks than peers based on the main Monterrey campus, where cohort sizes, and therefore economies of scale, were larger. The experience of ET turned a spotlight on the potential for online learning to level-up opportunities for students at smaller campuses, to foster collaboration between campuses, and to share expertise and resources with all students, regardless of their location.

In early 2020, a new second-year block was under development – *Biotechnological Tools in Solving Food and Health Problems* (BioTech Tools) – to be delivered at the Monterrey campus and replicated at other Tec de Monterrey campuses by separate teaching teams. The pivot to ET presented a new opportunity to integrate these teaching teams, and to co-design a single online version of the block that was available to all students. The 'core' Tec21 competencies embedded into the block were *decision-making* and *integrity*. Taking a user-centred design approach, the block's challenge was to devise solutions to improve crop yield in a rural Mexican community facing reduced rainfall and poor soil quality.

The membership of each student team tackling the *BioTech Tools* challenge was drawn from across Tec de Monterrey campuses and disciplinary majors. This diversity was mirrored in the block's teaching team, whose membership included faculty from five Tec de Monterrey campuses with disciplinary specialisms spanning Food Science, Biotechnology Engineering, Pharmaceutical Biology and Agriculture. Indeed, feedback from the first cohort of students participating in the block suggested that the breadth of expertise in the teaching team helped them to better understand the relevance of their own disciplinary specialism both to the block's theme and to the challenge.

Driven by its success in bringing together learning across disciplines and campuses, the Biotechnology block will continue to be offered in a fully online format. Indeed, as Tec de Monterrey transitions beyond ET, it will take a blended approach to delivering many of its Tec21 blocks, with the modules delivered online and the challenges delivered face-to-face.

[34] Tec21: https://tec.mx/en/model-tec21

6.3. Assessment practices

Interviewee feedback pointed to a step-change in assessment practices in engineering undergraduate programmes worldwide as a result of ET, with a *"move away from big, handwritten, invigilated exams in huge exam halls"* towards a wider range of more flexible assessment approaches.

The two decades leading up to ET had seen major transformations to engineering curricula worldwide. While teacher-centred 'lectures' had often remained the dominant pedagogical approach, the use of active, collaborative and experiential learning had increased markedly, with an introduction of new activities to build students' professional capabilities in areas ranging from critical thinking to entrepreneurial mindsets. Many interviewees noted, however, that while a growing number of engineering schools had enabled such pedagogical and curricular changes, the methods used to assess student learning often remained untouched. Some went on to suggest that, although new formative assessments (assessments that advance learning) may have been embedded into courses, this often came <u>in addition to</u>, rather than <u>instead of</u>, existing summative assessment (assessments that grade learning).

The online pivot turned a spotlight on the volume of assessment undertaken in many undergraduate programmes and the proportion of the academic calendar devoted to invigilated written exams: *"you suddenly get a picture of the scale of how much assessment you do when you've got a spreadsheet of it and you've got to go line-by-line and work out how you're going to replace things, it's just immense"*. ET was also noted to have highlighted deep inconsistencies between course learning outcomes and the topics covered by assessment, with learning in areas such as professional skills or sociotechnical contexts often absent from exams. As one interviewee commented, *"if you don't put anything on the exam related to these things, then it's like saying to the students, no, it doesn't really matter"*.

As noted in Section 4.3, the online pivot forced root-and-branch changes to assessment systems in engineering programmes worldwide. Many programmes focused attention on replicating synchronous proctored written exams within the online environment. Others, however, took the opportunity to *"try out new ways to assess"*: over half of interviewees spoke about their involvement in pilots of alternative assessment practices during ET, often working in collaboration with educational developers, colleagues, and/or students in their design and delivery. These new assessment practices included *"open-book, 24-hour exams"*, group projects, one-to-one oral exams, and continuous 'low-stakes' graded quizzes. Their selection was often guided by a desire to provide more authentic ways to assess, ones that offered students flexibility, encouraged deep learning and captured a greater breadth of learning outcomes. Many went on to highlight the positive outcomes of these pilots which had, in many cases, *"burst a lot of myths… that some of these [online or alternative] methods of assessment would never work, or are just unreliable, or would take too much time"*. In particular, the fact that some assessment systems, such as oral exams, could be *"cost neutral in terms of teacher time"* when compared to written exams clearly came as a surprise to many. Despite the success of many of these pilots, however, interviewees went on to note that *"the elephant in the room that we have to deal with is the cheating"*.

As noted in Section 4.3, ET brought the issue of academic misconduct to the fore, with many interviewees reporting a sharp increase in student plagiarism and widespread concerns about *"a lot of undiscovered cheating"* during online assessments. At the same time, strongly-held views were also expressed about the future role of proctored exams and the need to look beyond the maintenance of academic integrity as the overriding priority in the design of assessment systems. For example, one engineering school leader spoke of their grave concerns about calls for online proctored exams to be rolled out more widely across their university in the coming years:

> *"Ideologically, I just dislike it… It starts from the position that the student is inherently dishonest, and given half a chance will cheat… That can't be where we start from. We can look at how we mitigate the small number that might want to cheat as part of the process, but if that's the starting point of your design, that students are inherently dishonest, I think you're in the wrong business".*

Although a range of perspectives was evident, the majority view was that *"the time has come to rethink how and why we assess"* in engineering schools such that 'advancing student learning' rather than 'preventing cheating' is the primary design consideration. As one instructional designer noted:

> *"when you design assessment, I think you have to start with validity. You have to start by thinking 'how can this influence the students so that they learn better and they learn the right things?'… I prefer that we design assessment around validity first and then try to fix the loopholes around the edges to make it sufficiently reliable, so making it robust against cheating and making it fair for the students".*

It was also suggested that this transformation in assessment would not be achieved by eradicating or imposing particular forms of assessment. Interviewees instead advocated the adoption of a wider range of assessment practices – including written invigilated exams – tailored to the learning outcomes of each course and offering students a diverse set of experiences that spread their workload across the academic year. Many went on to express *"a sense of real optimism"* that the pilot practices developed during ET would form the foundation for a more diverse and dynamic approach to assessment across the engineering education sector. Three forms of assessment that grew in prominence during ET were expected to play an important role in this new landscape:

1. **Synoptic assessment:** a single piece of assessment – such as a written exam or project – that calls upon students to connect and apply their learning from across multiple courses. Several engineering leaders noted an interest in establishing programme-wide assessments *"that model want we want of our students… [which is] to take a holistic view of their learning… not just know stuff, but know how it interrelates, be able to connect things together and draw from different sources"*. One example was the *Capstone Assessment* system adopted by UCL in 2020 for all first-year assessments at university, which was described by one interviewee as *"a single piece of assessment, a self-reflection, that synthesised how students achieved their learning objectives for the year"*. Across UCL Engineering, this *Capstone Assessment* ranged from an open-ended *"robotics build"* in the *Electronic and Electrical Engineering* programme, to a reflective series of essays on how students had met the competencies set out in their disciplinary professional engineering standards in the *Civil, Environmental and Geomatic Engineering* programme.
2. **Oral exams:** a one-to-one spoken exam where students present *"how they have met the [course] learning outcomes"* and/or respond to targeted questions from instructors. Oral exams were characterised as assessment systems where *"students know they cannot get away with a shallow understanding… they know they will have to stand and face the teacher and show that they really understand"*. They were also noted to offer a mechanism for instructors to explore *"the limits of students' understanding"* in an authentic setting that connects the teacher with the learner. An example of the application of oral exams is given in Box 12, taken from the KTH Royal Institute of Technology (KTH) in Sweden.
3. **Low-stakes continuous assessment:** where *"learning is broken down into the smallest of bits"* and students engage in low-stakes assessment throughout the course. One interviewee who had adopted this approach during ET noted, *"the units are so small that it's relatively easy to [pass each one]. I think the most important part is that you get into the rhythm. Then you'll put in effort and learning is unavoidable. And also it disincentivises cheating because of the sheer number of these units*

> *and the pass/fail nature. I have not had a single student argue about a grade"*. One example of such an approach, taken from Harvard University, is given in Box 13.

Interviewees highlighted several engineering schools and universities that had already adopted systemic changes to their assessment systems in light of the lessons learnt during ET. For example, in 2021, Singapore Institute of Technology shifted its policy to require only 30% of assessment to be exams-based, down from a threshold of 70% prior to ET.

While anticipating greater diversity and flexibility of assessment practices in the future, interviewees also noted several practical barriers that are likely to work against their wider adoption. For example, some suggested that *"unless there is some positive momentum"* to retain effective assessment practices adopted during ET and *"understand what we can learn from them"*, programmes were likely to revert to the *"safety"* of pre-ET assessment practices. It was also reported that current administrative and budget allocation models in universities do not incentivise deviation from traditional invigilated written exams. For example, while an instructor adopting alternative assessment approaches carries the risk and development costs entirely themselves, a colleague who chooses to assess via written invigilated exams benefits from substantial institutional support through, for example, the centralised administration of exam papers, *"the block-booking of the sports halls ready for exams"*, or the appointment of invigilators. As one interviewee noted *"if I was a vice rector, I would create a level playing field where the written exam is not invisibly subsidised by the university. I would have every assessment format... carry its own cost"*.

Box 12: **Sailing for Performance, KTH, Sweden**

Theme highlighted: **Use of oral exams**

Sailing for Performance is an applied-mechanics course at KTH in Sweden. In the words of the course lead, Professor Jakob Kuttenkeuler, it *"challenges students to try to solve the equations of motions and equilibrium to calculate how a sailboat, as a machine, works"*.

The course is graded via two forms of assessment: ongoing project work and a closing individual 25-minute oral exam. Jakob worked closely with an educational developer at KTH, Dr Kristina Edström, in the years leading up to ET to hone the design and focus of the oral exam. They concluded that two elements proved crucial to the successful adoption of oral exams in this course.

The **first** is to *"hand over the first seven minutes of the exam to the student"* to demonstrate how they have reached the course learning outcomes. As Kristina explained *"we reverse the burden of proof, and it really makes a difference in student motivation and the quality of learning, because they know that, at the end, I'm going to have to show Jakob that I really understand"*. The remaining 18 minutes is then devoted to follow-up questions that further explore students' understanding. Jakob noted how this approach minimises both instructor preparation time and opportunities for plagiarism:

> *"I don't have to prepare the questions I'm going to ask, because those pop up in my mind while I hear them talk... it comes very naturally. So each and every oral exam for each and every student becomes different"*.

The **second** crucial element is that the oral exam is only assessed on *"a coarse grading scale of: fail, pass and brilliant"*. This simple judgement is made during the oral exam and weighed with other course assessments to produce a final grade A-E. Grades are assigned during the oral exam, and (as with all assessments at KTH) students can retake the exam if they wish to attempt to improve their grade. To reduce the risk of bias and ensure fairness in grading, however, as Kristina noted, the instructor must consider the learning outcomes and clearly establish *"the quality thresholds, what is the understanding we look for for a pass and for a brilliant"*.

ET brought few changes to the design of these oral exams. Only the setting for the exam changed, moving from Jakob's office on campus to an online Zoom meeting.

Box 13: **Introductory Physics, Harvard University, US**

Theme highlighted: **Continuous, low-stakes assessment**

The approach to peer instruction[35] pioneered by Professor Eric Mazur has informed practices across engineering education worldwide. A major testbed for these innovations has been AP50[36], an introductory physics course at Harvard University for 'non-majors', many of whom are engineering students. Over the past three decades, the focus, pedagogy and structure of AP50 have changed progressively, year-by-year, including the introduction of project-based learning, the focus on fostering empathy and the move from individual to team-based learning. The COVID-19 pandemic, however, precipitated the single biggest change to the course design to date.

Harvard University pivoted to online learning in March 2020, mid-way through delivery of AP50. With only three days to prepare, students were given the materials they needed to complete their projects from home and all remaining timetabled classes were delivered via Zoom. Eric Mazur, however, took the summer vacation to fundamentally redesign AP50 for the online environment. As he noted: "*rather than asking myself 'how do I translate what I am doing online?', I started with the question 'what can I do online that I couldn't do in the classroom?'*".

What emerged was a radically different approach. Three distinctive features stand out.

Firstly, the course was restructured around a fixed weekly schedule, scaffolded according to Bloom's Taxonomy[37] and managed through Canvas[38]. To foster individual accountability, students first completed activities and assignments alone, asynchronously, before moving on to tackle them with teams-mates, both asynchronously and synchronously. The course culminated in a multi-week team-based project; in 2020/21, one project tasked teams to build a self-propelled vehicle that they could use as an instructional tool to teach physics to high school students.

Secondly, peer instruction was delivered asynchronously using 'student-paced' learning: support was scheduled, using *Slack*[39] messages, at a time convenient to the student rather than the instructor. As Eric noted, *"one of the shortcomings of peer instruction is that the answer comes in [from the instructor] at the centre of the bell curve, so there are huge inefficiencies for the faster thinkers and for students who haven't got to the answer yet"*. Instead, teams asked for and received help when they needed it most.

Thirdly, *specifications grading*[40] was introduced. Rather than a single 'high stakes' assessment, AP50 was disaggregated into 68 micro-units that were each assessed using a pass/fail system. These units were spread across nine different activity types, including self-assessment, project presentations and weekly assignments. Students were able to retake these assessments as often as they liked during the week. As Eric noted, *"the units are so small that it's relatively easy to meet specifications. The most important part is that you get into the rhythm, then learning is unavoidable"*.

A range of measures were employed to monitor the impact of the new approach. This included a survey of student experiences, which indicated a significant increase in the perceived levels of both challenge and instructor/peer support for the revised 2020/21 AP50 when compared to previous years.

Looking beyond ET, Eric hopes to retain the online approach to AP50 forged in 2020/21, with only the team-based project work returning to a face-to-face format. As he noted, *"I've done my best teaching ever in the last year. I can say that with certainty and to a large degree"*.

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[35] Peer instruction: https://mazur.harvard.edu/research-areas/peer-instruction

[36] AP50, Harvard University: https://canvas.harvard.edu/courses/88146

[37] Bloom's Taxonomy: https://www.bloomstaxonomy.net

[38] Canvas learning management platform: https://www.instructure.com/en-gb/canvas

[39] Slack: https://www.slack.com

[40] Specifications grading: https://www.insidehighered.com/views/2016/01/19/new-ways-grade-more-effectively-essay

6.4. **Mindsets and wellbeing**

It was suggested that ET had catalysed new attitudes towards the importance of mental wellbeing in engineering learning and the role engineering programmes should play in fostering students' mindsets.

Over the past two decades, the set of graduate learning outcomes defined by engineering programmes worldwide has broadened considerably, with increasing priority given to students' mindset development. This builds upon a recognition that engineers in the 21st century must draw upon professional mindsets or 'ways of thinking', as well as professional skills and knowledge, as they are called to address the increasingly complex problems facing society and industry. Interviewee feedback suggested that this emphasis on student mindsets is likely to intensify in the years following ET.

COVID-19 and ET turned a spotlight on the importance of fostering student competencies that would help them to navigate this unprecedented period of stress and uncertainty. While some were professional skills (such as the ability to master digital tools or manage projects remotely), it was students' mindsets that were noted to play a crucial role in their capacity to operate effectively in the ET environment. For example, **empathy** was one mindset repeatedly discussed by interviewees, and one noted to heavily influence students' capacity to enable effective teamworking and build communities of peer support in the online domain. Another mindset discussed consistently by interviewees was **resilience**, defined by one interviewee as the capacity *"to accommodate and overcome challenges"*.

When discussing students' mindset development during ET, the topic that dominated interviewee feedback, however, was that of student **mental wellbeing**. COVID-19 and ET brought the issue of mental health to the fore, through both exacerbating the challenges facing students and *"making faculty more aware"* of the issue. These experiences were also noted to make explicit the relationship between the design of engineering programmes and the wellbeing of the students enrolled in them:

> *"where before [ET, faculty] said, 'gee, this is an incredible pace and pressure. This can't really be healthy', and then they shrugged it off and moved on. Now they're saying, 'no, this is having real impacts'".*

Prior to ET, the consideration of student mental health within engineering schools had typically focused on identifying the sub-group of 'at-risk' students and referring them to specialist university-wide or regional support services. Whilst this essential work continued during ET, it was often combined with new efforts to nurture the wellbeing of <u>all</u> engineering students. The idea that engineering schools should play an active role in fostering student wellbeing was noted by interviewees to represent a profound change and one that many expected to be retained at their institution in the future.

As interviewees looked beyond ET, they anticipated that student mindset development would become increasingly prominent in leading engineering programmes worldwide. In addition to fostering mindsets that strengthened the social, technical, and economic impact of graduate engineers (which had been a growing priority prior to ET), the next generation of leading engineering programmes were also expected to build mindsets that help students and graduates operate effectively in complex and dynamic working environments. Interviewees also expected that some leading engineering programmes would take a coordinated approach to fostering student mindsets, offering a range of mechanisms to build these competencies progressively throughout the undergraduate curriculum, with a particular focus on areas such as resilience, empathy, self-determination and mental wellbeing. One example of such a coordinated approach to foster student wellbeing is given in Box 14, with the focus on 'care' in the engineering school at Pontifical Catholic University of Chile (PUC).

Interviewee feedback also pointed to two factors that might hold back such change. The **first** was the capacity of engineering instructors to design and deliver effective programmes to foster student mindsets; simply put, *"do we have the people we need to make this happen?"*. The **second** was *"making room in the curriculum"* for such activities. A repeated theme of interviewee feedback was the reluctance of engineering instructors and leaders to reappraise programme priorities, and remove or scale-back the courses/content that add less value to student learning as new experiences/activities are added. As a result, concerns were raised that efforts to improve student wellbeing *"ironically might have the opposite effect that we want, because it adds more load to students"*.

Box 14: **Care initiative, Pontifical Catholic University of Chile, Chile**

Theme highlighted: **Supporting student mental wellbeing**

Since 2013, the PUC School of Engineering has enabled major changes to its undergraduate education. One focused on what was termed 'care': to foster engineers who care about their impact on the country and on society, and to establish a caring environment for learning that prioritises student wellbeing.

Following civil unrest in Chile in 2019 and COVID-19 restrictions from early 2020, both of which forced all engineering learning online, the need to support student wellbeing came into sharper focus. An early task for the 'care' initiative was an audit of the school's undergraduate programmes, to identify 'caring' practices that had a positive impact on student wellbeing with a view to propagating these approaches more widely. For example, one effective practice identified was a professor who reached out to students who exhibited a dip in their academic performance to ask whether they needed any help or support. Building on this practice, the school embedded what are termed *Wellbeing Teaching Assistants* (*TAs*) into selected 'high-enrolment' courses (with student cohorts of 400 or more). With students' prior consent, each *Wellbeing TA* liaises directly with 'underperforming' students to identify challenges they may be facing and devise (where appropriate) strategies to support them based on personal need. Depending on the circumstances, *Wellbeing TAs* have dispensation to offer flexibility over assignment deadlines, provide additional academic support or refer the student on to other support services.

As well as interventions to support those facing particular difficulties, the school also sought to embed activities to improve the mental wellbeing of all students. One example is the '*Science of Wellbeing*' course, launched as an elective in the school in 2021. The course lead, Professor Jorge Baier, had been motivated by his own efforts to improve his mental wellbeing and productivity as he cared for his autistic son: *"because I am a computer scientist, I wanted to know about the data, the science of what worked"*. Working with an educational physiologist, and taking inspiration from well-regarded practices worldwide[41], Jorge developed a course that centred on evidence-based practices to improve wellbeing. Each week of the *Science of Wellbeing* course focuses on a topic associated with mental wellbeing, such as self-care, kindness, materialism, and meditation. Students are first asked to explore and debate the topic in groups, before practising one of the techniques through an assignment. Speaking as the second iteration of the course was being delivered, Jorge noted *"we have an assignment going on right now where students have to do three acts of kindness… and keep a log of what they did, what was their reaction and the reaction of others"*. Students then come together to reflect on their assignments and discuss the research evidence connecting these behaviours and practices with mental wellbeing.

As PUC Engineering looks beyond ET, it aims to ensure that wellbeing is an ongoing strategic priority. As a result, the CARE Unit was established in the school in 2021, to identify and embed practices to improve the wellbeing of all members of the school's community.

[41] Such as Yale University's *Science of Wellbeing* course: https://www.coursera.org/learn/the-science-of-well-being

6.5. **Flexible, collaborative learning spaces**

Recent decades have seen the emergence of a new generation of engineering learning spaces designed to promote active, student-led learning and foster, for example, 'in class' collaborative learning (such as the *TEAL* classrooms at MIT[42]) and cross-curricular innovation and exploration (such as the *Innovation Space* at Eindhoven University of Technology[43]). While such on-campus spaces had become more common prior to COVID-19, much of engineering learning in universities worldwide still took place in lecture theatres designed around tiered rows of fixed seating, particularly during the early years of undergraduate study. Interviewee feedback suggested that the investment needed to transform traditional lecture theatres to student-centred learning spaces was often considered prohibitively expensive and high-risk at a time when teacher-centred lectures remained the dominant pedagogy.

A repeated theme of interviewee feedback was the ways in which the prolonged experience of remote learning had catalysed a fundamental reassessment of the design and function of the university campus, and *"moved the conversation about the redesign of our learning spaces into the mainstream"*. In this context, a significant minority of engineering schools and university leaders spoke about their intentions – either in the short- or longer-term – to reshape the design of their on-campus spaces. In the words of one university vice president: *"previously we used the campus mainly for lecturing, for tutorials, but we could do so much more with it"*.

Interviewees pointed to three factors driving this step-change in priorities for learning space design.

The **first** factor was the anticipated widespread adoption of blended learning: *"our physical estate is going to have to change quite rapidly to support this mixed mode of delivery"*. Prior to ET, institutional priorities for on-campus spaces were noted to have focused on *"fitting as many bodies as possible into a room"*; the experience of ET had shifted the debate for many to *"doubling down on what requires real in-person brick and mortar experiments and experiences and spaces, and moving everything else online"*. In place of lecture theatres with fixed rows of seating, interviewees pointed to two broad categories of learning space needed to support a new generation of blended engineering programmes. One is open, highly flexible spaces that can be utilised during scheduled, synchronous classes that allow instructors to adopt a range of approaches, be that peer learning, group project work, lectures or coaching sessions. The other type of space is *"open-access hubs for students"*: flexible social spaces and bookable 'pods' where students can engage in asynchronous learning either independently or collaboratively with peers. Interviewees pointed to several examples where existing engineering learning spaces are being redesigned to accommodate a student-led approach to blended learning. An example of changes already being made in this direction is the Technical University of Munich in Germany, where three raked lecture theatres (seating 300–400 students) are being converted into flexible collaborative spaces designed to *"activate the students, bring the students together"* during both synchronous and asynchronous learning.

The **second** driver was the increased need for technology-enabled learning spaces. Although a range of views were expressed with regard to the integration of technology within engineering learning spaces, most interviewees noted that, as a result of COVID-19, *"technology in our courses is here to stay – in how students access their learning, in how they collaborate, in how we assess our courses – and this changed reality will be reflected in the physical infrastructure, the places where they learn"*. Many considered it too early to predict the form that this might take. In particular, feedback was strongly

[42] TEAL (Technology Enabled Active Learning): http://icampus.mit.edu/projects/teal/

[43] TU/e Innovation Space: https://www.tue.nl/en/education/tue-innovation-space/

divided on the viability of hybrid learning as an effective and sustainable pedagogical approach. Some – the majority of those expressing a view – reported that:

> *"hybrid is unsatisfactory for everyone, the students in the room and the students at home, unless you have four or five instructors and incredible technology, it's just too difficult to get a dialogue going, it stifles interactivity… we are better going with 100% online or 100% in person".*

Others, however, suggested that hybrid *"is the way of the future, where students can learn wherever suits them best"* and attributed problems to the absence of *"better tech and better training"*. It is interesting to note, however, that the majority of interviewees spoke about ways in which the learning spaces at their institution had been adapted to accommodate hybrid learning, some as a temporary measure during ET and others in anticipation of a sustained pedagogical change that would allow students the flexibility to access their education either online or in-person.

The **third** – and perhaps most far-reaching – factor catalysing change is a fundamental revaluation of how the campus footprint be used to add most value to student learning and development, and, as one vice-dean stated: *"it is not to sit 200 18-year-olds in a poorly ventilated, dimly lit lecture theatre for two hours at a time, it's got to be something that is really meaningful"*. In the words of another university leader, the experience of ET had *"forced the question 'what is a campus good for?'"*. Indeed, many noted how the experience of ET had shone a light on the vital and unique role played by the university campus in enabling social connections, cultures and identities across the student community that, in turn, underpinned their learning and development. As they worked to build back on-campus *"vibrancy"* following the transition out of ET, interviewees repeatedly spoke about how their institutions had started to look more critically at its physical environment and the relationship between learning space design and the development of student identities and communities of support. The form that this new generation of on-campus spaces should take was a major topic of interviewee feedback. Although two activities were noted to be priorities for engendering inclusive cultures and identities – hands-on experiential learning and unstructured student peer-to-peer interactions – it was the latter, the *"space for human interaction"*, that interviewees spoke about at length. They pointed, in particular, to the role of on-campus spaces in fostering '*serendipitous interactions*', the unplanned ways in which students meet and connect with one another while on campus, perhaps while walking between buildings or working within a maker-space. These unscripted interactions and informal cross-community interactions were described by one interviewee as *"the life-force for [building] students' identity and passion and sense of belonging"*. The development of spaces that foster such interactions was clearly a priority to many. Overall, interviewees anticipated the emergence of a new generation of flexible, student-centred learning spaces that would blur the lines between classrooms and social/networking hubs, and support peer-to-peer collaborative learning. In the words of one interviewee: *"I think that the days of raked lecture theatres are gone… it's the informal learning spaces that we will need: flat flexible spaces that are a blend between learning and social are going to be the new common spaces that will be developed".*

While cautioning that changes to on-campus learning spaces would take time – *"new buildings are big money and big money moves slowly"* – interviewees highlighted several examples where the lessons learnt from ET has already influenced the design priorities for campus redevelopments. One example, from the Norwegian University of Science and Technology (NTNU) in Norway, is outlined in Box 15.

Box 15: **Campus redesign, NTNU, Norway**

Theme highlighted: **Learning spaces to foster identity and community**

In 2019, NTNU launched a programme of systemic reform to its engineering undergraduate programmes. Called *Technology Education of the Future* (FTS), it seeks to embed an experiential and active learning approach that calls upon students to addresses real-world engineering problems, particularly those centred around the UN Sustainable Development Goals. At the same time, NTNU is also planning a major campus redevelopment[44]. Responding to the merger of NTNU with several regional colleges and the drive to foster interdisciplinarity, the redevelopment will bring two disparate campuses together in a single university footprint in the Norwegian city of Trondheim. The construction of the new campus will begin in 2024/25.

Planning for this campus redevelopment comes at a time of considerable flux at NTNU, as it implements the FTS vision and transitions back to campus following the lifting of COVID-19 restrictions. The experience of ET, however, had also allowed the university to 'stress test' some innovative pedagogical approaches and challenge some fundamental assumptions about what engineering learning spaces should look like. For example, while the FTS vision points to the need for more flexible learning spaces that support experiential learning, prior to 2020, many in the NTNU community had remained unconvinced that foundational first-year engineering courses could be delivered effectively without the use of large auditoriums. However, the experience of ET, together with the outcomes of FTS pilots, demonstrated that a blend of asynchronous online and in-person small-group learning was both possible and effective in these introductory, large-scale courses, without the use of auditoriums.

The closure of NTNU campuses for much of 2020 and 2021 also prompted fundamental questions to be asked about the future role played by a university campus, such as, *"what is it that can be done on the campus that cannot be done elsewhere?"*. Feedback garnered from across the NTNU community suggested that, beyond workshop and laboratory spaces, two interlinked features would prove crucial in establishing a campus that supported and enriched the engineering learning experience: *building students' identity* and *academic companionship*.

Building students' identities – in and beyond their discipline – was understood to be a critical function of the new NTNU campus, as a means to foster student engagement, motivation and competence development. In particular, the establishment of a unified NTNU footprint was seen as an opportunity to foster a sense of belonging and shared identity that set the university apart from national and global peers. Indoor and outdoor spaces that bring students together around shared interests or identities will feature prominently in the new campus.

Academic companionship – friendships and communities of support rooted in shared learning and problem-solving – was also identified as an integral part of NTNU's new campus and one that was sorely missed during the online pivot. Indeed, experiences during ET suggested that informal peer learning and support are not only beneficial during directed, in-class activities or student projects, it can also enrich independent student-led learning. In particular, outcomes of 2020/21 FTS pilots – such as the first-year *Statistics for Engineers* course – pointed to the benefits of students coming together on campus with peers to reflect upon and discuss asynchronous learning components of blended courses, rather than conducting this work alone. Informal, flexible spaces that support unstructured peer-to-peer learning and interaction will therefore be placed at the heart of the new campus.

[44] NTNU campus redevelopment: https://www.ntnu.edu/campusdevelopment

6.6. Co-produced educational strategies

Recent decades have seen a massive growth in university-based expertise and support in engineering teaching and learning. These include in-house engineering education research centres, dedicated labs for pedagogical development and instructional support, and a growing cohort of educational innovators pioneering new practices. However, interviewees noted that, with notable exceptions such as the *Institute of Education*[45] at Tsinghua University in China, this growing capacity and expertise has had limited impact on strategic educational policies and priorities at their home schools or universities.

Interviewee feedback suggests, however, that the experience of ET has enabled a step-change in practices and priorities, with in-house expertise and pedagogical research likely to play a more prominent role in shaping institutional policies for teaching and learning in the future. A central element of this shift was the rapid, agile and community-informed approach to educational decision-making that emerged at many universities during ET. Soon after the online pivot in early 2020, some universities brought together ad-hoc strategic decision-making committees, typically comprising faculty and student representatives, as well as experts and university leaders in areas such as pedagogical development, educational technology, student support and educational design. Often taking a highly consultative approach with student and academic communities, these committees steered many of the major educational decisions and strategies adopted during ET. As one vice president commented:

> *"the educational leadership, we were way more effective than we ever have been… we learnt how to make effective and quite well-grounded decisions in the short time… instead of having one question going from one forum to another forum, we understood that we need to have several [specialist] functions in presence at the same time without hierarchy… this way of working will sustain somehow".*

ET also precipitated root-and-branch strategic reviews at a significant minority of engineering schools and universities worldwide to chart a future educational direction based on the lessons learnt from this unprecedented period (as outlined in Section 2.4). Often acknowledging ET as a major turning point in educational cultures, practices and priorities, these strategic reviews, again, frequently drew on widespread community engagement as well as in-house educational expertise. Taken together, these community-informed approaches to educational strategy development are likely to have a legacy beyond ET: many of the ad-hoc committees established to steer decision-making during ET appear to have transitioned to permanent strategic advisory groups, and recommendations laid out in reviews of post-COVID education are already being taken forward by a number of institutions.

While this trend towards agile, evidence- and community-led decision-making in teaching and learning is one noted to have been enabled by the experience of ET, such approaches were already apparent in isolated exemplars. For example, two centres that were in the pipeline prior to the online pivot were the *Institute for Advanced Study in Problem-based Learning* at Aalborg University, Denmark, as explored in Box 16, and the *Institute for the Future of Education* at Tec de Monterrey, Mexico, as explored in Box 17.

It should be noted, however, that this move towards inclusive, evidence-led policy-making was not the experience and expectation of all interviewees. As explored further in Section 8.1, a core group of interviewees expressed major concerns about the ways in which their institution had curtailed autonomy and side-lined pedagogical evidence in educational policy-making during ET and were pessimistic in their assessment of how cultures and practices might change in the coming years.

[45] Institute of Education: https://www.ioe.tsinghua.edu.cn/en

Box 16: **Institute for Advanced Study in PBL, Aalborg University, Denmark**

Theme highlighted: **Blending research, external engagement and practice**

In January 2022, Aalborg University launched the *Institute for Advanced Study in PBL*[46] (IAS-PBL) to advance research, innovation, and practice in PBL at the university. The institute brings together several existing centres in teaching and learning from across the university, including the *Aalborg Centre for Problem-based Learning in Engineering, Science and Sustainability under the Auspices of UNESCO* (UNESCO Centre[47]), the *Centre for Digitally Supported Learning*, and the university's *Learning Lab*. These existing units – and most notably the UNESCO Centre – bring together globally-recognised research and innovation in PBL with a suite of external engagement and consultancy activities that support a worldwide network of instructors, pedagogical researchers, and policy-makers in the field of PBL.

The IAS-PBL also establishes an explicit connection between this existing institutional expertise and the educational policies and practices adopted across Aalborg University. So, for example, the Director of the IAS-PBL has joined senior officers, including the university vice-president, on the strategic university council that determines institutional educational policies. IAS-PBL will also oversee the delivery of major institution-wide educational reforms, such as the introduction and development of interdisciplinary *MegaProjects* and the adoption of programme-wide blended learning (see Box 21, Section 7.6).

Box 17: **Institute for the Future of Education, Tec de Monterrey, Mexico**

Theme highlighted: **Blending research, external engagement and practice**

The *Institute for the Future of Education*[48] (IFE) was established at the Tec de Monterrey in December 2020 with a mission *"to drive research, innovation, and entrepreneurship in educational innovation by collaborating with professionals worldwide to meet today's educational challenges and create the future of higher education and lifelong learning"*. The IFE is focused on three interrelated areas:

- **interdisciplinary educational research** addressing five 'grand challenges' in higher education and lifelong learning. Early projects focus on STEAM education, student retention, and how to foster students' complex thinking. Through the *IFE Living Lab and Data Hub*[49], institutional and global researchers are given access to anonymised educational data from Tec de Monterrey students, faculty, and alumni to explore and advance new educational research ideas.
- **advancing educational practice at Tec de Monterrey** through applying and piloting educational research ideas and innovations within the university's Tec21 curriculum[34] and lifelong learning provision. This evidence-led approach, that brings together Tec de Monterrey educational researchers with peers worldwide, is supported by tools such as an incubator and accelerator for educational technology start-ups, a technology transfer unit specialising in educational technology and an annual competition[50] focused on the skills gap in Latin America.
- **building partnerships** that inform and advance evidence-led educational change worldwide. Mechanisms for network-building and external engagement include the *Observatory*[51] website and newsletters on educational advances and *International Conference on Educational Innovation*[52], the largest educational innovation conference in the Spanish-speaking world.

[46] Institute for Advanced Study in PBL: https://www.iaspbl.aau.dk
[47] UNESCO Centre: https://www.ucpbl.net
[48] Institute for the Future of Education: https://tec.mx/en/ife
[49] IFE Living Lab and Data Hub: https://ifelldh.tec.mx/en
[50] TPrize: http://tprize.mx/en/#about-us
[51] Observatory: https://observatory.tec.mx
[52] International Conference on Educational Innovation: https://ciie.itesm.mx/en/

7. **Acceleration of existing trends**

Chapter summary:

This Chapter outlines the ways in which COVID-19 and ET are anticipated to have accelerated changes to the priorities, practices and cultures that were already in train in engineering programmes prior to 2020. Interviewee feedback suggested that ET was likely to advance change in six major areas:

Section 7.1. Blended learning: in addition to a repository of new asynchronous learning materials, the wider adoption of blended learning at a course and programme level.

Section 7.2. Social and environmental responsibility: an increased prominence given to sustainability and social responsibility in both the curriculum and the culture of engineering schools.

Section 7.3. Global collaborations and partnerships: increased engagement and new opportunities for global partnerships to improve engineering teaching and learning.

Section 7.4. Digital learning: values-led digital learning strategies that enable a new generation of educational technologies to emerge in engineering programmes in the coming years.

Section 7.5. Flexible and lifelong learning: the growing prominence of flexible learning pathways and lifelong learning opportunities in engineering.

Section 7.6. Scaffolded competency development: the development of programme-wide scaffolding to support the progressive development of student competencies over time.

7.1. **Blended learning**

Interviewee feedback suggested that ET would enable a rapid acceleration in the adoption of blended learning across the engineering education sector.

ET brought a substantial growth in the prevalence of blended approaches in engineering learning worldwide. Interviewees noted that two factors would drive its continued growth in the coming years. The **first**, and most prominent, was student demand: as they emerged from ET, students have become increasingly vocal in their calls for the continued adoption of flexible online learning that they can access independently, at a time that suits them, while working either alone or with peers. The **second** driver was a broad-based recognition of the benefits that blended approaches can offer to engineering student learning. In particular, many noted how well-crafted asynchronous resources paved the way for a greater emphasis on authentic and collaborative learning during on-campus synchronous experiences. In the words of one director of teaching and learning:

> *"if there's one thing that we might have learnt during the pandemic, it's that some of that transmission of information can be done just as effectively, if not more so, using small bits of asynchronous material and that we use the time that we have with students for interaction, for discussion, for hands-on activities and group work for practicals, labs, whatever, but you really make that time count".*

Taken together, interviewee feedback indicated that three different 'levels' of adoption of blended learning are likely to become increasingly visible in engineering schools and universities in the future:

1. **Repository-level:** a 'repository' of asynchronous online resources that would be made available to students to complement their learning. It was anticipated that the materials developed during ET would go on to form the basis of institutional "*resource banks*" that would not only support learning across most curricular courses but could also be deployed for lifelong learning opportunities. Many interviewees, however, sounded a note caution around the quality and evidence-base for the online resources developed during ET. It was widely reported that much of this material produced *"was a digital replication of teacher-centred lectures"*. In particular, concerns were raised that universities would not dedicate time and resources to improving the quality of these materials after the transition out of ET and therefore that *"a lot of these one-on-one copies of traditional educational materials will remain over time"*.
2. **Course-level:** the adoption of blended learning within individual courses. It was anticipated that many of the instructors who adopted blending learning during ET would retain this approach in the future (while typically switching to face-to-face delivery for the synchronous portions). It was also anticipated that many would build on these approaches to *"be more intentional about using active learning techniques"* during synchronous on-campus sessions as well as working to improve the design and quality of asynchronous resources.
3. **Programme-level:** the adoption of programme-wide blended curricular designs that combine independent student-led online learning with authentic in-person collaborative projects. In the years prior to the pandemic, a new generation of engineering programmes emerged whose curriculum was designed around distinct face-to-face synchronous and online asynchronous components, often taking the CSU Engineering programme[53] at Charles Sturt University in Australia as inspiration. Examples included Iron Range Bell Program[54] in the US, and TEDI-London[55] in the UK. Based on this model, all technical engineering content (the 'engineering science fundamentals') is disaggregated into series of online of 'micro modules' that students access asynchronously and independently to help them address the authentic on-campus team-based challenges that punctuate the curriculum. While many in the engineering education community had been interested in such models prior to ET, progress to deliver on such visions within existing engineering school had been slow. Interviewee feedback suggested that the experience of ET had emboldened such change efforts and heightened capacity for engineering schools and universities to reform their curriculum around programme-wide blended models. In particular, this experience had both validated the benefits of self-directed asynchronous student learning and helped to amass significant online resources to enable and accelerate such a transformation.

Two universities noted to be moving towards a programme-level blended learning model – where their curriculum combines self-directed asynchronous online courses with on-campus experiential problem solving – are Aalborg University in Denmark and Tec de Monterrey in Mexico (as outlined in Box 11, Section 6.2). One example of a new-start programme-level adoption of a blended approach is given in Box 18, from Munster Technological University in Ireland.

[53] CSU Engineering: https://www.csu.edu.au/engineering/home
[54] Iron Range Bell Program: https://www.ire.minnstate.edu/bell.html
[55] TEDI London: https://tedi-london.ac.uk

Box 18: REEdI, Munster Technological University, Ireland

Theme highlighted: **Programme-wide blended learning approach**

Funded by a €9m grant from the Irish Higher Education Authority (HEA), *Rethinking Engineering Education in Ireland*[56] (REEdI) is designed to foster agility and innovation in engineering education across the country. The REEdI consortium brings together partners from higher education, industry and research centres, with experts in engineering education and digital learning technologies. REEdI is designed to deliver two products.

The **first, and major, product** of REEdI is the establishment of a new four-year bachelor of Mechanical and Manufacturing Engineering (MME) at Munster Technological University (MTU), launched in September 2022. Inspired by CSU Engineering[53] in Australia, the REEdI approach combines in-person project- and work-based learning with remote self-directed learning via a bespoke online platform. The first two years of the MME programme are structured around a series of on-campus authentic team-based projects, and the final two years are structured around projects embedded in work placements within manufacturing companies. In addition to an ongoing programme of self-reflection, students' progress and learning in these projects are advanced via a series of short modules delivered online via what is termed the REEdI Topic Tree. Through the Topic Tree, MME learning outcomes are divided into a series of micro modules (or 'leaves') that students typically access asynchronously and independently (although synchronous on-campus learning is also built into the early semesters of the programme). The Topic Tree offers an interactive visual map that illuminates the inter-dependencies between each curricular element, allowing students to identify how optional modules or different learning pathways might map onto prospective future careers.

A distinctive feature of MME – and one which sets it apart from the CSU Engineering model – is its use of immersive technologies to support learning and assessment. Virtual reality (VR) and augmented reality (AR) experiences are embedded throughout the Topic Tree, which students can access either from home using a VR headset provided to them on enrolment or via an on-campus immersive suite. While off-the-shelf VR solutions are likely to be used for topics focused on professional skill development (such as practice presentations and interviews), the modules and experiences specific to engineering learning will be designed by an in-house team of VR specialist developers. One driver for REEdI's use of VR/AR technologies was to offer an inclusive education, with equality of access for all students including those with disabilities, and those studying part-time or accessing their education remotely. The experience of ET laid bare the challenge of delivering meaningful hands-on engineering experiences for students learning online. As a result, REEdI's ambitions for the development of new AR/VR technologies has grown significantly. For example, as well as supporting learning of the engineering science fundamentals and professional skills, it was decided that all MME laboratory experiences and many industry 'site visits' should also be designed and delivered online via the Topic Tree using AR/VR.

The **second product** of the REEdI initiative will be to establish the Topic Tree as a stand-alone resource accessible to engineering students and professionals worldwide. Students and instructors in all REEdI partner schools will be given full access to the Topic Tree free of charge. Beyond this partner group, the Topic Tree will be made commercially available for universities and colleges worldwide and for individuals engaged in continuing professional development. The income stream this generates will be used to support the ongoing operation of the MME programme and to further expand the Topic Tree, including the development of new immersive technology resources.

[56] Rethinking Engineering Education in Ireland: https://reedi.ie

7.2. **Social and environmental responsibility**

Interviewee feedback suggested that the themes of environmental and social responsibility will become increasingly visible in engineering programmes worldwide, particularly in the US.

Environmental and social justice – the ethical obligation to act in the best interests of the environment and society at large – was a major focus of interviewee feedback. Interviewees reported that these themes had grown in prominence in engineering programmes worldwide in the years prior to ET. They pointed to increasing calls, from across the community, for a new generation of programmes that trained engineering graduates to be *"ethically aware and socially responsible, not just technically brilliant"*.

Building upon this momentum for change, experiences during 2020/21 were reported to have reinforced the commitment to embed social responsibility and sustainability in engineering education:

> *"in terms of the global responsibility piece, I think it was coming... I don't think COVID has deviated the track, I think it has accelerated it... it has heightened a view of social justice [and] shift of thinking about what [an engineering] career is, and what students want, and what impact they want to make".*

To many, the experience of *"living through a pandemic... [had] demonstrated the humanity of us"* and underscored the need to *"put the human in the centre of everything we do"*. As one interviewee put it, *"all these 21st century problems that we engineers need to solve, whether its global warming, whether it's the next pandemic... at the core of it is people, is humans"*. At the same time, ET was noted to have brokered a new connectivity between instructors and students, from one where *"you walk in the classroom and the students are the students and we don't have to think about it as much"* to one where *"we were suddenly 'seeing' the students, and the complexity of their lives, for the first time... we've become so much more aware of who our students are and what the student's needs are"*. Again, this experience was one that brought social responsibility to the fore, with an increasing recognition of the diversity of barriers faced by the student community. Awareness was heightened by the movement for racial equality catalysed in 2020, during the early months of ET. As a result, some interviewees, particularly those based in the US, reported that the most passionate and far-reaching conversations across their academic community during ET centred around diversity, equity and inclusion (DEI). As one university leader noted, *"the place where I am seeing different attitudes emerge is in the DEI space... We have always taken pride in the diversity of the student body, and I think that what has come out [in 2020/21] is that that's probably not enough... people are thinking about how can we be deliberate in moving that needle".*

Interviewee feedback suggested that, taken together, these changing priorities and expectations were likely to impact engineering education in two ways. As discussed below, these impacts relate, firstly, to the engineering curriculum and, secondly, to the culture and opportunities in engineering schools.

The **first anticipated impact** was an increased prominence given to sustainability and social responsibility in engineering curricula. As one interviewee put it, *"building in this idea of responsible innovation and how we bring together ethics, sustainability and global responsibility"*. While the mission statements of engineering programme often centre around themes of *'educating graduates able to tackle the world's most pressing problems'*, interviewee feedback suggested that few programmes took a systematic approach to equipping students with the socio-technical knowledge, skills and attitudes necessary to enable such transformations. Instead, discussions about social responsibility and mechanisms for sustainable development had often been confined to free-standing 'ethics' classes and final-year electives, or used to provide a real-world context for project-based problem-solving. In contrast, it was anticipated that the next generation of leading engineering schools would take a more integrated approach to building students' *"human-centred capabilities, like empathy, humility and ethical* *thinking"* as well as their capacity to *"understand the social or environmental context in conjunction with the technical context"*. Several interviewees went on to suggest that the consideration of 'ethics' in many engineering programmes may also transition from focusing on *"fairly binary black-and-white micro ethics questions that have very little to do with some of the complex realities of engineering work"* towards addressing global questions that are rooted in the collective values and responsibilities of engineers.

When describing the form that such changes might take, interviewees often pointed to existing US-based exemplars in which social responsibility has been threaded throughout the curriculum, such as the programmes at Olin College of Engineering, the *Integrated Engineering* programme[57] at the University of San Diego, and the *Human Centered Design & Engineering* programme[58] at the University of Washington. Many such exemplars relate to programmes that are relatively small and new. A greater challenge may lie in integrating such learning pathways in established programmes with larger student cohorts. These efforts may be advanced by proposed changes to the US engineering accreditation system (ABET) currently under review to sharpen the focus on DEI in engineering programmes[59], an amendment proposed by the deans of 10 major US engineering schools in 2021.

The **second anticipated impact** was to the prevailing culture in engineering schools. Around a third of interviewees noted the need for schools to *"establish a culture that is equitable and does not exacerbate existing inequalities…. ensuring that all students are given equal opportunities to thrive and advance"*. Some went on to suggest that *"our whole system is based on a set of principles that have built-in discrimination and marginalisation and exclusion, they're just built into the system in ways that we don't see"*. Several engineering leaders spoke about a personal mission to address cultures and practices that had left them feeling marginalised during their own engineering education: *"I don't want anybody to feel like I felt in graduate school or in some of the classrooms I was in"*. It was suggested that DEI activity in engineering education had historically focused on recruiting under-represented groups, particularly women and minority ethnic groups, rather than adapting the cultural environment in engineering schools to reflect, support and nurture the whole student community. As one interviewee commented, the key questions should not be *"how do we toughen up this population of individuals to survive in the current system?…[but] how do we change the system to be more welcoming?"*. Interview feedback suggested that what was needed most was a change in culture and a critical examination of the informal support mechanisms in place: *"so part of the challenge [for many faculty]… is providing explicitly to all students, those things that you [already] provide implicitly to those students that you feel most comfortable with"*.

Many interviewees noted that change would not be easy and would take time. Some, however, suggested that schemes that have proven effective in addressing systemic gender inequality in STEM – such as SEA Change[60] in the US and Athena Swan[61] in the UK – offered important insights into the types of systemic approach that would be needed to address inequality across the board.

It is interesting to note that the two impacts described above – where social responsibility is placed at the heart of both the **curriculum** and the institutional/school **culture** – are reflected in the new mission of Olin College: *'Transforming engineering education toward a world in which engineering serves everyone'*. Launched in 2022, this mission is articulated in two components: *'Engineering serving everyone'* (i.e. preparing Olin's graduates to "*do good in the world*") and *'Engineering education for everyone'* (i.e. with programmes that welcome and nurture the talents of students of all backgrounds).

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57 Integrated Engineering, USD: https://www.sandiego.edu/engineering/undergraduate/integrated-engineering/
58 Human Centered Design & Engineering, University of Washington: https://www.hcde.washington.edu
59 ABET Diversity, Equity and Inclusion: https://www.abet.org/about-abet/diversity-equity-and-inclusion/
60 SEA Change: https://seachange.aaas.org
61 Athena Swan Charter: https://www.advance-he.ac.uk/equality-charters/athena-swan-charter

7.3. **Global collaborations and partnerships**

Cross-institutional and cross-national collaboration has been a growing feature of the global engineering education landscape in recent decades. Interviewee feedback suggested that ET was set to transform and advance such partnerships and connections, driven by two factors, as outlined below.

The **first** was a broader recognition of the benefits that cross-institutional collaborations can offer. Most interviewees pointed to one or more ways that ET had brokered new and/or strengthened their existing networks in engineering education *"for the better"*. These collaborations took a range of forms. Some noted how informal partnerships and the development of common ET strategies with regional peer universities had *"created a deeper trust"* and opened up new opportunities for collaboration between such institutions. Others spoke about how their global engineering education communities had *"flourished"* during ET, often because the online format had allowed them to reach beyond *"the people who could afford to come to the [in-person] conference or the meetings"*. These positive experiences of working with and learning from global peers was noted to have built both willingness and capacity for cross-institutional collaboration, laying a foundation for greater connectivity across the sector.

The **second** factor was the ways in which ET had built confidence, competence and familiarity with online tools that can enable and advance remote collaboration. Many interviewees reported that they were now engaging, or planning to engage, in new opportunities for remote global collaboration that they would not have considered to be feasible prior to ET: *"the pandemic has taught us that it's easier to do these things than we thought".* Examples highlighted included:

- ***global student projects:*** ET forced the abandonment of student mobility and global exchange programmes. In response, many engineering schools sought to offer alternative global and inter-cultural experiences through establishing courses and projects that connect students from universities worldwide via video-conferencing. For example, during ET, the engineering school at Uniandes in Colombia co-designed three new online courses in collaboration with partner universities worldwide that brought together these student cohorts in collaborative projects and activities. Interviewees engaged in such developments enabled during ET noted that they offered students many of the benefits of global exchange programmes at a fraction of the cost and time commitment associated with international travel. As a result, it was widely anticipated that such global projects would be sustained and advanced in the coming years.
- ***external partnerships for pedagogical change:*** several interviewees – including many based at institutions highlighted as 'current' and 'emerging' leaders in engineering education in the 2018 MIT study[1] – reported that *"we've had an incredible increase in enquiries"* from other universities seeking guidance and support in how to deliver active and collaborative learning remotely during ET. Many went on to suggest that the use of online tools, such as virtual whiteboarding, during ET had exposed a wealth of new opportunities to deliver such external support and training remotely. One example, from Olin College of Engineering, is outlined in Box 19. Interviewed feedback also anticipated that a greater number of pedagogical development and PhD programmes in engineering education would be offered partially or fully online in the future, making such training and development opportunities *"accessible to a lot more countries"*.

When asked how ET might impact future collaborations in the sector, there was one area where no interviewee consensus emerged: that of co-creating a shared online set of *"globally-curated materials"* for foundational engineering courses. Some interviewees noted that ET had highlighted *"the crazy situation where we are all spending so much time teaching the same thing: the same course in maths, in statics, in electronics"*. They proposed that sharing course materials across universities and countries would offer students access to higher quality learning resources while *"freeing up time"* for instructors to enrich in-person learning. As a result, some anticipated the emergence of a new educational landscape where curated resources for foundational courses were created and shared as open-source materials. Other interviewees, however, argued that such moves would place an unacceptable constraint on instructor autonomy in the focus, design and coherence of their courses and would therefore not be widely accepted by the community.

Box 19: **External engagement, Olin College of Engineering, US**

Theme highlighted: **Cross-institutional collaboration and learning**

Since welcoming its first cohort of students in 2002, Olin College of Engineering has progressively built its 'external engagement' ambition to inspire and catalyse positive change in teaching and learning across the higher education sector. During the College's first decade, these activities primarily focused on inspiring new models for engineering education by showcasing the College's distinctive experiential, student-led educational approach to the wider community, through talks, campus tours, and bespoke workshops. Building on the increased global visibility this generated, Olin has established a growing number of partnerships with universities worldwide to co-design systemic reform to their engineering programmes. A major constraint on Olin's external reach and impact, however, has been its capacity. With a total faculty population of 45, external interest in engaging with Olin has far outstripped the College's capacity to support it. This challenge has been compounded by Olin's approach to external engagement that has often mirrored its approach to educating its on-campus students: activities are typically based around immersive, face-to-face interactions with Olin faculty.

The online pivot in March 2020 offered a unique testbed to explore and trial alternative delivery modes for the College's external engagement activities. Despite the challenges faced, several benefits quickly became apparent. One was to connect the College with a broader and more diverse external audience. As Jessica Townsend, Professor of Engineering at Olin, noted:

> *"pre-COVID, we had a mindset of a premium given to being in-person... but as soon as we stepped into the freedom of the virtual space, you are no longer tethered to 'how many people can we fit into the [Olin] dining hall?', 'how do we get people to where we are?', 'how many [Olin] faculty are willing to travel?' All those logistics melt away".*

Indeed, the online *Summer Institute* professional development workshops delivered by Olin free-of-charge in June 2020 saw an enrolment of 300 global participants, more than four times the number attending equivalent in-person workshops in previous years. In addition to such practical benefits, the online delivery mode also enabled Olin to offer more immersive experiences to its external partners. For example, Professor Jason Woodard, Dean of External Programs and Partnerships, described how a demonstration during an online *Summer Institute* workshop (using the virtual whiteboarding tool Miro[25]) enabled external faculty to experience Olin's education from the student perspective:

> *"the students led this co-design activity on a Miro board, getting commentary and feedback from [Olin faculty]... it blew people's minds. There's just a certain level of intimacy in being able to observe a learning experience that you can get in a virtual world that goes way beyond anything we've ever done before".*

Olin is currently undertaking a strategic review of its priorities, scope and reach in external engagement. While in-person interactions will continue to play a major role, the online pivot has undoubtedly unlocked new modes and markets for external connection and collaboration. As Jason noted, the insights gained have, *"opened up the possibility for much broader engagement at scale, in lower-touch but still impactful way... including delivering a regular virtual programme".*

7.4. **Digital learning**

Interviewee feedback pointed to the profound impact of ET on the place of digital learning in engineering education. Interviewees anticipated change in the use and design of learning technologies at both the institutional level and the engineering programme level, as discussed in turn below.

Institutional level: ET was noted to have 'stress tested' university digital learning strategies at a scale that had never been imagined. While pointing to *"a lot of mis-steps"*, many interviewees suggested that ET had enabled a strengthening and *"recalibration of our digital strategy"* as institutions were called to address fundamental questions such as *"what is the purpose of technology in learning?"*. Many also went on to suggest that the period of experimentation and *"trial by fire"* during ET had likely accelerated the digitalisation process *"by over a decade"*. They pointed to institutional development in three areas:

1. **capacity:** the experience of ET was noted to have laid bare the levels of expertise, personnel and investment needed to operate an effective, institution-wide digital infrastructure, and building the foundations to put these components in place.
2. **strategic alignment:** interviewees pointed to several examples of where ET had facilitated an alignment between universities' 'teaching and learning' strategies and their 'digital learning' strategies. For some, this worked to bring together previously disparate education reform programmes, often opening up new opportunities for student learning and exploration. At several engineering schools and universities worldwide – such as École Centrale Casablanca in Morocco and Eindhoven University of Technology in the Netherlands – the pandemic coincided with parallel systemic efforts to both *"improve digitisation"* and embed challenge/problem-based learning. In many cases, ET was noted to *"bring these two projects together"* by *"accelerating our way of thinking and... combining challenge-based learning with online materials"* through the widespread adoption of blended learning.
3. **guiding values:** for some, ET provided an impetus to articulate a set of core values to underpin institutional digitisation strategies. In the words of one dean, *"what do we stand for? what are the principles that we hold up?"*. Several interviewees spoke about a *"personal ethical code"* that they followed during ET in strategic decision-making and course design: to *"always put the students first... if it does not help students, we should not do it"*. Many went on to note the importance of articulating an equivalent set of institutional values – such as embedding DEI or promoting student collaboration – to guide the university's future approaches to digital learning. For many, this process was crucial to ensuring that the digital learning strategy supported and advanced, rather than worked against, the university's values. So, for example, in early 2022 and following months of internal discussion and development, Aalborg University announced four 'principles' that would underpin its institution-wide digital strategy: variation in learning experiences; student empowerment; collaboration and openness; and flexibility and diversity.

Programme level: interviewees also spoke about the likely future impact of ET on the use of digital learning tools and technologies in engineering programmes in the coming years. They often discussed the changes in three distinct categories – one impacting practice almost immediately, one rolling out in the coming few years, and one that may take a decade or more to evolve – as outlined below.

The **first set** of changes was anticipated to be the improvement and integration of educational technologies that became normalised in engineering schools worldwide during ET. Interviewees pointed to a range of tools that were rapidly adopted following the online pivot in early 2020, such as Zoom, Miro[25], and Piazza[23]. Tools to support digital simulation, modelling, remote labs and digital twins were also widely embraced to facilitate lab sessions and design-build activities, many of which were developed in-house. While these technologies were often not new to engineering education, their widespread adoption was noted to offer new opportunities to improve student learning and flexibility during and beyond COVID-19 restrictions. ET was characterised as a time when both instructors and students were willing to pilot different technologies, often taking a cooperative approach to determining how and when different tools were best employed. Interviewee feedback suggested that many would build upon this exploratory approach in the years following ET, with these digital learning technologies set to become more prominent in engineering courses and programmes.

The **second set** of anticipated changes was to LMSs and digital course platforms. ET was noted to have demonstrated many of the strengths of universities' existing LMSs. For example, instructors noted the benefits of being able to track the time spent by students working on various asynchronous materials and the levels of success achieved in assessment, allowing them to rapidly identify *"topics that students are struggling with or any student that might be spending too much or too little time"* engaged in these activities across the cohort. At the same time, however, interviewees pointed to a range of limitations of their institution's existing learning platforms. The most pressing amongst these was the continual need for students and instructors to download or navigate to different digital applications for different course elements: *"for each separate task in the class – the team formation, the assignment, the meeting – there was a separate tool, which makes remote learning really hard"*. As another professor noted, *"you're continually shifting environments… I call it death by a thousand clicks for so many of our systems… if software is taking more time to manage than it is saving in the classroom, then all these lessons are going to be lost"*. Interviewees highlighted the need for a new generation of digital course platforms that embed all the key digital tools *"in the background of learning"* such that students can navigate between them seamlessly without disruption to the flow of the class. In this context, some interviewees pointed to two pioneering platforms that hold considerable potential in this area: *Engageli*[62], a new higher education learning platform designed to foster active and collaborative learning, and *Forum*, the learning platform developed by and used at Minerva University, as outlined in Box 20.

The **third set** of changes was a new generation of educational technologies that could address some of the most urgent challenges facing engineering education. Several interviewees suggested that the experience of ET had shifted engagement with digital learning from *"a small group excited by technology"* to *"a wider group of instructors using technology to solve problems"*. Broader conversations were noted to have emerged across engineering schools about how technology could be used to address questions like *"how can we make learning more flexible?" or "how can our courses be more inclusive for underserved groups?"*. In particular, three educational challenges were highlighted for which high-potential educational technologies could form a critical part of the solution: (i) offering personalised, student-led learning experiences to large student cohorts at publicly-funded universities; (ii) fostering engagement, trust and collaboration for students engaged remotely in group project work; and (iii) offering no-cost engineering learning opportunities to underserved communities such as refugees. When asked to identify best practices where this new generation of educational technologies were being used in practice, however, few interviewees were able to cite existing examples. Instead, they often pointed to institutions that were pioneering new innovations using educational technologies or piloting early-stage technological developments. In this context, the developments at ASU (including innovations such as Dreamscape[63]) and MIT Open Learning (including innovations such as ReACT[64]) were frequently cited.

[62] Engageli: https://www.engageli.com
[63] Dreamscape: https://www.dreamscapelearn.com
[64] MIT Refugee Action Hub (ReACT), MIT Open Learning: https://openlearning.mit.edu/engagement/mit-react

Box 20: **Forum, Minerva University, US**

Theme highlighted: **Flexible digital learning platforms**

Minerva University is a liberal arts and sciences university, launched in 2012 with an ambition to establish a new global blueprint for higher education.

Three features set the Minerva approach apart. The **first** is its 'residential online' model, where students live and learn from seven different cities worldwide – San Francisco, Seoul, Hyderabad, Berlin, Buenos Aires, London, and Taipei – taking their classes online and moving location approximately every six months. The **second** is an approach to active learning rooted in collaborative discussion, blending online synchronous learning with in-person projects embedded within the various communities in which students are based. The **third** is the university's focus on progressively building students' competencies: Minerva has defined 80 *Habits of Mind* and *Foundational Concepts*[65] (divided across the four core competencies of critical thinking, creative thinking, effective communication, and effective interaction) that together are developed and tracked across the four-year degree. Students are continuously assessed against these competencies using a range of measures, including their in-class verbal contributions, in-class quizzes and group projects.

Each of these distinctive features is underpinned by Minerva's bespoke digital learning platform, Forum[66] that has been specifically developed to drive active and collaborative learning. This educational technology brings together a range of functions and tools (such as course development, polling, multi-stream video, and interactive whiteboards) within a single virtual learning environment.

Through this single, integrated platform, Forum is designed to allow both students and instructors to devote their undivided attention to student learning, rather than to managing technology or keeping track of lesson plans. So, for example, from the **students' perspective**, Forum offers what is termed a 'dynamic classroom' allowing them to interact with peers during class while at the same time (for example) working collaboratively on a computer code. It also provides an 'outcomes index' dashboard allowing students to track their progress over time either by course or by competency and to review associated formative feedback from instructors. From the **instructor's perspective**, Forum allows them to track their lesson plan, activity-by-activity, during synchronous sessions and make tools (such as polling) available to launch at the appropriate point in the session. It also allows instructors to monitor the progress and in-class contribution of each student in real time, enabling them to focus attention on any topics that students are struggling with.

Minerva University's established online learning approach meant that COVID-19 restrictions had only a limited impact on its activities and operations. The pandemic, however, appears to have had a greater impact on the levels of ambition expressed by clients to the Minerva Project[67], the for-profit company that helps external partners to embed core elements of the Minerva model in their own institutions. As the Managing Director of Higher Education Innovation at the Minerva Project noted in late 2021:

> *"the thing that's changed the most in the last year…. [has been] folks coming to us and saying 'we need to build something new'. This isn't about plugging little pieces into existing programmes, or finding a fancier version of zoom… they want an entirely different learning experience for students".*

Several institutions globally are working with the Minerva Project, integrating interdisciplinary curricula and active learning into their programmes, including the University of Miami (US), Esade (Spain), and Zayed University (United Arab Emirates).

[65] Habits of Mind and Foundational Concepts: https://www.minerva.edu/public/media/enrollment-center/Minerva-HCs-Intro.pdf
[66] Forum: https://www.minervaproject.com/solutions/forum-learning-environment/
[67] Minerva Project: https://www.minervaproject.com

7.5. **Flexible and lifelong learning**

Over the past decade, flexible learning has been a growing priority in engineering education worldwide, for example through offering new opportunities in remote learning and student choice at the undergraduate level, and by providing graduates and the wider community with new avenues for lifelong learning. Interviewee feedback suggests that the experience of ET and the widespread adoption of online learning would intensify the drive for increased learner flexibility.

Their feedback suggested that three impacts of ET were at the heart of this acceleration:

- **awareness of market opportunities:** a greater appreciation of the potential markets for flexible, remote, work-based or lifelong learning opportunities. Indeed, many engineering schools and universities with an existing profile in online and/or lifelong learning noted a rapid increase in both interest and participation with these products during COVID-19 restrictions.
- **faculty engagement:** a broader understanding among the academic community of what online and/or lifelong learning actually is. Prior 2020, faculty engagement with the creation of lifelong learning resources (such as MOOCs or micro-credentials) was characterised by several interviewees as *"a side-project that only one or two people in [the department] got involved with"* and whose impact was often not visible to colleagues or line managers. Interviewee feedback suggested that the experience of ET had *"opened up to a lot of people what lifelong learning really means… having seen where we've gone with COVID, I can get a better idea of how it might work"*. Many noted that, often for the first time, faculty were now able to recognise the role that they might play in designing and delivering flexible and/or remote experiences.
- **upgrade of infrastructure:** a rapid improvement in the infrastructure, resources and capacity to deliver flexible/online learning: *"in the space of three months [in late 2020], we had amassed more online [resources] than we have in twenty years. Not all of it is great, but as a starting point, it is astonishing what has been achieved"*. Indeed, almost half of all deans consulted spoke about plans to convert online courses developed during ET into lifelong or flexible learning resources. For example, the number of lifelong learning courses offered by KTH in Sweden increased from around 10 pre-ET to over 120 in 2022, with applicant numbers for these resources rising from 500 to 4500 over the same period. In the coming years, KTH plans to increase the proportion of its educational provision devoted to lifelong learning from 1% to 20%.

Interviewees highlighted a range of ambitious plans to build new capabilities and programmes in flexible learning at engineering schools and universities across the world. For example, Singapore University of Technology and Design is developing significant new capacity in 'cyber-physical learning', blending educational technologies with both in-person and remote learning, as part of its strategy to attract new cadres of learners who may access all or part of their engineering education remotely.

While recognising that ET has offered a springboard to establish new opportunities in flexible learning, concerns were also noted. One was that the continued drive to establish flexible or remote learning pathways implies a scale of provision, resourcing and support that comes with considerable risk for smaller institutions. Interviewees pointed to several exemplars that addressed this issue. For example, the *EuroTeQ Campus*[68] initiative brings together six European technical universities to share online courses, connecting students from across institutions and building economies of scale for each course.

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[68] EuroTeQ Campus: https://euroteq.eurotech-universities.eu/initiatives/building-a-european-campus/

7.6. **Scaffolded competency development**

ET was expected to accelerate an existing trend towards 'scaffolded' competency development in engineering programmes, an approach that enables all students to progressively build and reflect upon their individual professional competencies over time, regardless of the learning pathway taken.

Engineering instructors and programme leaders spoke about how ET had prompted them to critically re-examine the ways in which their curriculum nurtures and builds students' professional competencies – such as conflict management, problem analysis or critical thinking – over the course of their undergraduate studies. They noted, in particular, two key questions that ET brought to the fore:

1. **If engineering programmes are to offer greater flexibility and choice, how do we ensure that <u>all</u> students progressively build a core set of professional competencies, regardless of the learning pathway taken?** Not only could *"students get lost very easily"* as they navigate a diverse range of opportunities, it was noted that increased flexibility could, if not designed thoughtfully, *"undermine the integrity, the purpose of education". As one interviewee noted, "the whole concept of becoming an engineer is not just taking scattered micro-credentials, it is figuring out your identity"*. Establishing frameworks that are both independent of the learning pathway taken and take a structured approach to progressively building students' professional skills, mindsets and identities were therefore anticipated to emerge as key priorities for the future.
2. **To what extent are the approaches adopted by engineering programmes to nurture students' professional competencies both evidence-led and effective?** Competencies such as empathy, time management and resilience often lay at the heart of students' capacity to navigate ET. However, this period was also noted to have laid bare an implicit and problematic assumption in the design of many engineering curricula: that simply exposing students to a situation where a particular competency (such as empathy or time management) would be beneficial, implies that they have been taught (and thereby have mastered) that competency. One interviewee characterised this assumption as: *"if we just throw students into a team, they'll somehow learn all of the [professional] skills that they need and the job is done"*. A second priority articulated by many interviewees was therefore to *"inject some rigour"* into how engineering programmes build students' competencies, beyond simply offering team-based experiences.

Prior to 2020, several engineering schools and universities had started to address these issues head-on by establishing programme-wide scaffolding to support progressive professional competency development. As described below, such approaches typically brought together three components:

- **dedicated training and development in key professional competencies**, via explicit, and evidence-based workshops scheduled throughout the undergraduate programmes.
- **a programme-wide framework to build upon such competencies over time**, including, for example, a curricular structure that calls upon students to apply these competencies to problems/challenges of increasing complexity as they progress through their studies.
- **ongoing mentorship** to help students reflect upon and document their individual competency profile such that *"they have a helicopter perspective on their competencies… so each learner knows what they can do, what they cannot do, and are able articulate this profile to an employer"*.

Two examples of programmes that recently adopted a scaffolded approach to developing students' competencies are *Tec21* at Tec de Monterrey in Mexico (where each semester of the curriculum is assigned core learning outcomes that are nurtured regardless of the learning pathway taken, as outlined in Box 11) and the undergraduate programmes at Aalborg University, as described in Box 21.

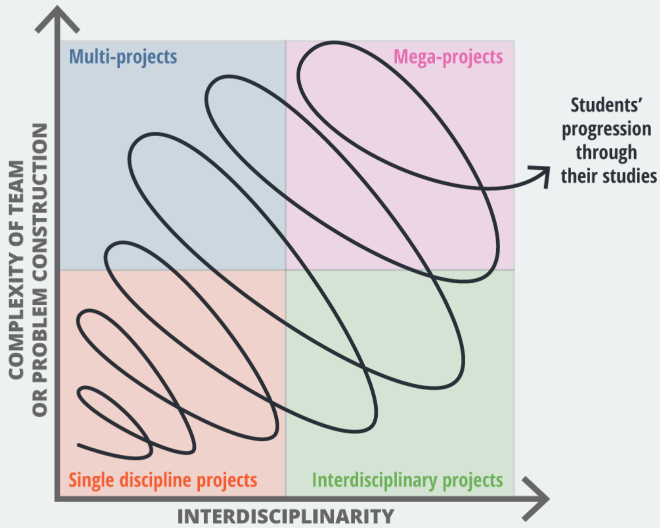
Box 21: PBL Competencies, Aalborg University, Denmark

Theme highlighted: **Progressive and structured development of competencies**

Since its foundation in 1974, Aalborg University has taken a distinctive PBL approach to its research and education activities[69]. Half of the undergraduate curriculum is devoted to group projects that each span a full semester, with the remaining half devoted to disciplinary-based 'taught courses'. The group projects are underpinned by a student-led and team-based pedagogy: students are expected to identify and define their problem, as well as manage and source the materials needed to deliver their project.

In 2018, Aalborg launched a major reform to its PBL pedagogy to combine a flexible, interdisciplinary approach with scaffolding that allows students to progressively build, practice and strengthen what are termed PBL Competencies throughout their studies. In addition to the establishment of a new digital learning infrastructure, two inter-related threads are central to this reform, as outlined below.

The **first thread** is to embed a progression in the complexity and interdisciplinarity of projects tackled by students throughout their programme. In the words of one interviewee, this approach aims to ensure that *"students do not get stuck in a rut of working on the same types of projects in the same way"* but instead experience variety in both the construction of the project and complexity of the problem over time. This step-by-step progression builds from the first year of study and culminates in an opportunity for students to engage in the newly-established *MegaProjects*[70] in the final semesters of study. Framed around one or more of the UN's Sustainable Development Goals, *MegaProjects* challenge students to address authentic multi-factored, interdisciplinary problems as part of a network of inter-connected teams drawn from across the university. The ultimate goal is to equip university graduates with the competencies, and the adaptability, to tackle any type of challenge facing society, regardless of the problem complexity and the project construction.



The **second thread** is to ensure that students are equipped to conceptualise, reflect upon and showcase the competencies they have developed. Since early 2021, all engineering students at the university have been asked to build a 'PBL Competency Profile' which provides a self-reflective analysis of their experiences, achievements and strengths. This portfolio, and the quality of self-analysis it contains, is assessed via an individual oral exam. Throughout their studies, students' profile development will be guided by structured self- and peer-reflection sessions. In addition, each Faculty will identify priority competencies – such as conflict resolution or collaborating with external partners – whose development will be advanced through dedicated workshops embedded into the curriculum.

Further information about Aalborg University's approach to building student competencies over time is given in a case study on the CEEDA website[4].

[69] The Aalborg University model for PBL: https://www.en.aau.dk/about-aau/aalborg-model-problem-based-learning/

[70] Aalborg University MegaProjects: https://www.megaprojects.aau.dk

8. Concerns and risks for the future

Chapter summary:

This Chapter explores interviewee concerns on the challenges and risks facing the engineering education sector that stem from the experience of ET and COVID-19. Four concerns are highlighted:

> **Section 8.1. Institutional inflexibility:** that inflexibility will stifle innovation at some institutions.
>
> **Section 8.2. Exacerbation of inequalities:** that inequalities amongst students and instructors, and across institutions, may be exacerbated by COVID-19 and ET.
>
> **Section 8.3. Prioritisation of profit over learning:** that ET may promote a low-cost passive form of online learning that does not prioritise student learning and development.
>
> **Section 8.4. Risk of defaulting to the 'status quo':** that lessons will not have been learnt from ET.

8.1. Institutional inflexibility

When reflecting on the future of the engineering education sector and its capacity for positive change, interviewee feedback often fell into one of two quite distinct groups: the first of which expressed deep concerns about the future; the second of which was broadly optimistic. What distinguished these two groups appeared to be the levels of flexibility invested in instructors at their university during ET and the levels of community consultation that guided institutional decision-making during this time.

The **first group** of interviewees characterised the response to ET at their institution as *"restrictive"* and, in some extreme cases, *"dictatorial"*. They pointed to rules imposed that went far beyond those required by regional COVID-19 restrictions or by institutional IT/space constraints, and that tightly controlled, for example, what assessment systems instructors could adopt or the proportion of students that must be in-class during hybrid teaching. These top-down regulations were often noted to have been devised with limited meaningful instructor consultation, leaving many *"disappointed in the decision-making process and how it almost dehumanises the entire community"*. Interviewees in this group went on to suggest that the *"long shadow of COVID-19 and the way it was handled"* at their institution during ET had severely restricted the scope for instructors to both deliver student-centred learning and devise solutions to the challenges faced by student in real time. As a result, instructors were noted to be *"burnt out and disillusioned"* throughout and beyond ET, with limited capacity to foster or maintain new educational ideas or activities that did not clearly meet university regulations. This group also expressed widespread pessimism about the opportunities for positive change to engineering education at their institution in the future. In the words of one professor:

> *"the institutional responses of heavy-handed mandates, of increasing the pressures, I think has eroded a belief in the goodness of the system... Our administration has fundamentally damaged the relationship between leadership and faculty, staff and employees... we burned a lot of social capital unnecessarily in addition to wasting an opportunity for true innovation that could have happened".*

A **second** group (representing around half of instructors) described a very different ET environment, one which was supported by an inclusive decision-making process at their university. This approach was associated with a relaxation, rather than a tightening, of institutional regulations in teaching and learning, enabling instructors to take an experimental approach that was responsive to students' changing needs and priorities. So, for example, some interviewees in this group spoke about how their university/school had amended regulations governing course duration/structure during ET to enable participation in global student projects – where students form projects teams with counterparts at universities worldwide – as alternatives to hands-on engineering projects. Other interviewees spoke about how they had been given dispensation to replace written invigilated exams (that had hitherto been a mandatory course component) with alternative forms of assessment. Interviewees in this group, while pointing to deep concerns and challenges, also characterised ET as a time of experimentation and institutional cohesion. They were also broadly optimistic about the direction of travel for engineering education in the future and the sector's capacity for positive change.

Taken together, interviewee feedback pointed to an association between institutional flexibility during ET and the capacity of instructors to deliver responsive, student-led learning. Many went on to suggest that flexibility – or *"a loosening of the administrative rules"* – will play a critical role in driving positive change in the future. Interviewees characterised higher education as a sector in flux, with ongoing uncertainty surrounding many central questions such as the long-term impact of ET on student mental health and which graduate attributes will be prioritised by engineering employers in the post-COVID years. They also pointed to many new opportunities on the horizon in engineering education – such as through new assessment practices, digital learning platforms and global project opportunities – that will call for institutional flexibility to broker and embed.

8.2. **Exacerbation of inequalities**

The impact of ET and COVID-19 on inequalities in engineering education was a major focus of interviewee feedback. Some pointed to several examples of how ET had *"actually benefitted people who are traditionally disadvantaged by our system"*, such as the ways in which the online pivot had offered some in the disabled community *"an equality of access on the whole that wasn't true of the pre-pandemic offer"*. However, the major focus of interviewee feedback centred on how ET had both *"disclosed [existing] inequalities and created new ones"*. Particular concerns were voiced about inequalities amongst three groups – students, instructors and institutions – as outlined in turn below.

Inequalities amongst students. Based on their observations and experiences, interviewees raised a range of concerns about the impact of COVID-19 and ET on student inequality. One was whether *"some of the gains we may have been making in diversity and inclusion are going to be lost"* as a result of ET. For example, some spoke about how the online pivot had *"made it harder for underrepresented minority groups to be connected [with one another]... [introducing] a threat of longer-term losses to those communities"*. However, the major concern raised in relation to student inequalities centred on access to working spaces and digital inequality. In the words of one professor:

> *"what does worry me, and worries me considerably... is the digital divide of the students... when we talk of blended [learning] as if it's simple and everyone is going to be able to engage in it, I think we have to be very careful about what we're assuming our students can and can't do... technical skills, internet access, homelife, other responsibilities, all the sorts of things that you didn't notice when they were in person that I think we've seen so much more when they're in their own environment [during ET]".*

As they looked to a future educational landscape where online learning will play an increasingly prominent role, many interviewees suggested that the acute challenges faced by some students in accessing their learning from home during ET had not been fully recognised, let alone systemically addressed. They cautioned against moving forward with large-scale online or blended approaches without first understanding the working environment and digital access of all student groups and, building on this knowledge base, ensuring that the educational design does not exacerbate inequalities faced. As one interviewee put it, *"when you bring people on to campus and you put them in your environment, certain things are possible. When you're asking people to do things in their environment, you have to be much more cognisant of what that environment is"*.

Some went on to describe the long-term legacy of ET on particular student groups as a stark indicator of inequalities that might be *"baked into the system if we don't start taking student access to technology, student homelife into account"* in the design of engineering programmes. Interviewee feedback made clear that the challenges faced by students educated during ET were not evenly spread. While some saw *"a positive increase in attainment"* during ET (often attributed to student re-watching asynchronous videos), others struggled throughout ET to access large parts of their education and the communities of support that accompanied it. Concern centred on students from disadvantaged backgrounds and/or from regions with limited internet connectivity. Amongst these groups, some spoke with concern about *"a lost COVID generation"* who were *"lagging behind previous batches of students"* in both academic attainment and mental wellbeing. Interviewees from regions of Asia and Africa, in particular, pointed to a *"lack of technical capacity"* amongst students educated during ET, questioning whether *"industry is just going to write these students off"*. Indeed, several examples were cited of graduate engineering job advertisements *"saying that students who graduated in the COVID pandemic are not allowed [to apply]"*. Some went on to urge the global engineering education community to *"commit to providing internet and connectivity"* for future generations of students across the sector.

Inequalities amongst instructors. Several concerns were raised in relation to inequalities amongst instructors during ET, including sharp disparities apparent between those who could *"easily and comfortably work from home"* and those who could not. However, the issue raised most frequently was that of *"who took the burden"* of additional workloads in education and student support during ET and what impact this might have on their long-term career trajectory in academia.

While it was widely acknowledged that *"the workload of all our faculty, every single one of them"* increased during ET, many also noted that *"the burden of it all fell quite unevenly"*. In particular, it was repeatedly reported that *"caring for students, the well-being aspects, I think that's fallen quite disproportionately on women and on younger members of staff"*. Many voiced concern about the impact this may have had on the research progress made by these faculty groups during ET, and thereby its long-term effect on their career progression: *"they just haven't had the opportunity in the last couple of years to be applying for research grants in the same way. For earlyish career staff who were on teaching and research contracts, it will have been a real struggle for them to have maintained their research trajectories"*. Some interviewees expressed deeply-held concerns that, as a result, academic roles will become more polarised in the post-COVID higher education landscape, widening the divide between *"research-focused faculty and education-focused faculty"*, with student learning and support increasingly becoming the sole responsibility of the latter group. In the words of one engineering leader, *"I'm worried that in some places we're going to end up with segregation: the teaching-focused people are responsible for doing all the teaching... and the people who are predominantly research maybe contribute a bit of teaching, but they turn up, do their thing and go away"*.

At the same time, concerns were expressed about whether and how instructors that "*stepped up to the plate*" during ET might be recognised and rewarded by their universities and the role played by these contributions to their long-term career advancement. While it was widely reported that *"at the early stages of the pandemic, there seemed to be a kind of realisation in the whole community that teaching was really important"* (as noted in Section 4.5), interviewees often cautioned that this phenomenon might be short lived: *"there has been a lot of mumbling in departments about how teaching has been privileged throughout this process, and that research has taken a bit of a back seat… they want to move past it".* As a result, concerns were expressed that those whose made some of the most profound contributions to student learning and support during ET – particularly women and early-career academics – might find their career prospects *"side-lined"* in future years in favour of their research-focused colleagues.

Some interviewees, however, went on to point to a small but growing number of universities that were well-placed to address this issue via major recent changes to academic career pathways and institutional reward systems. What sets these institutions apart was noted to be a clearly articulated definition of 'educational leadership' – the individual's contribution to fostering an inclusive and supportive learning environment at a programme, school or institutional level – and flexible career pathways that offer 'educational leadership' as one route to advancement. Several interviewees pointed to new academic career frameworks at an institutional level (such as that embedded at UCL[71] in the UK) and national level (such as that under development for all Dutch research universities[72]) as examples of how educational leadership can be placed at the heart of university reward systems.

Inequalities amongst institutions. When reporting concerns about inequalities in the engineering education sector, the third area repeatedly highlighted by interviewees was *"a differentiation, a gap, between those universities that have the resources and those who don't".* They went on to suggest that this divide – separating universities by global reputation and by opportunities for educational innovation – had become more evident during ET and risked widening further in the coming years.

Institutional resourcing undoubtedly had a marked impact of the capacity of universities to adapt to ET and to address the myriad of challenges it presented quickly and effectively. Many of the solutions adopted – for example to replace written exams with online alternatives or to introduce hybrid learning – called for technology-based solutions that, in the words of one African university leader, *"universities like mine could never afford to pay".* For many universities, a lack of institutional resources was noted to have *"closed off"* opportunities for educational innovation during ET and had, in some cases, precipitated a default to *"the simplest ways to teach"*, principally transmissive 'lectures' through live or pre-recorded videos, sometimes undoing decade-long efforts to introduce active or student-centred learning. Similarly, as they looked beyond ET, concerns were expressed that many of the ET-related advancements in engineering education would be out of reach to all but the most well-resourced universities. In the words of one university leader in South America:

> *"the learning management systems, these tools that personalise education, the remote labs, virtual reality, all of these trends require very sophisticated technological tools and very expensive technology… there's no way to do this without money. And that's a real problem… no matter how enthusiastic I am, no matter how I train my professors… we need also money".*

In contrast, well-resourced universities have had the flexibility to invest in new technologies, infrastructure and personnel, and to take more exploratory and innovative pathways through and beyond ET. Several interviewees expressed deep concerns that these divergent experiences of ET might lead to *"a further stratification of engineering education… a risk that rich universities will be able to utilise new, sophisticated technologies to better set themselves apart… feeding into this bifurcation between the engineering education 'haves', and the engineering education 'have nots'".*

[71] UCL Academic Career Framework: https://www.ucl.ac.uk/human-resources/policies-advice/academic-career-framework-and-promotions-processes

[72] Recognition and rewards: Room for Everyone's Talent: https://recognitionrewards.nl

8.3. **Prioritisation of profit over learning**

When reflecting on the risks and challenges facing the engineering education sector as it transitions beyond ET, almost a third of interviewees voiced concerns that some of the current institutional efforts to broaden the adoption of online learning would be driven by *"purely economic reasons"* rather than for the benefit of student learning and support.

While ET was widely noted to have brought into focus new online tools and mechanisms to advance student learning and development, it was also noted to be a time when, by necessity, *"stop gap"* educational solutions that could be deployed rapidly were favoured over thoughtfully-designed, evidence-led online learning approaches. Indeed, interviewees repeatedly noted that much of the online learning delivered at their institution during ET *"was just making traditional teaching digital. It was taking the PowerPoint slides and all the parts of the worst kind of analogue teaching you can do – the 45-minute lectures or the one-and-a-half-hour lectures – and then you were putting them into Zoom"*. While of questionable benefit to student learning, such forms of online education are quick and cheap to deliver: without costly experiential, interactive or mentorship elements and without the need for on-campus spaces, such online 'lectures' can be scaled up to almost any student cohort size, offering a significant cost savings to universities. Deep concerns were expressed about the proliferation of such forms of online learning and the impact this might have on students' learning, mental wellbeing and communities of support. At the heart of these concerns was the question of whether universities and governments would emerge from ET with a continued prioritisation of *"being efficient over being effective"*. As one engineering professor commented, *"much of the pandemic has led us to think about efficiencies because those are driven administratively by cost concerns, and maybe not so much about what it takes to be really effective in our mission, which I would frame as human development"*.

Concerns focused specifically on whether, under increasing pressure from external commercial education providers, universities would call on engineering instructors and programmes to reduce the on-campus space intended for experiential or peer learning, and increase student cohort sizes without additional capacity to support individualised or small group learning. Indeed, several interviewees cited recent examples of being asked by their university to be a *"figure-head"* for a new high enrolment online course for which they would produce reusable video content but have no contact with participating students and for which little *"human-to-human contact or mentorship"* was planned.

Some interviewees went on to suggest that it may be difficult to make a compelling case against the proliferation of 'for profit' online courses at a time when COVID-19 and ET has left considerable deficits in university budgets worldwide. At the same time, concerns were expressed that the generation of engineering students educated under ET conditions who *"haven't had the same joy of working with others in person and have been used to watching videos of the lectures"* might not be well-placed to campaign against the dilution of the on-campus experiential or collaborative learning experience. As one interviewee noted, during the slow transition out of ET restrictions, *"we [currently] have a rather dead campus it seems, and we are not able to explain to students what they're missing out on"*.

When asked how such risks might be mitigated, several interviewees pointed to the importance of establishing a clear set of values to guide future priorities and practices – both online and face-to-face – in engineering education: *"we need to agree the purposes of education, or else we will be side-tracked from an economical or efficiency perspective"*. The educational values established at the University of Edinburgh and under development to guide digital learning at Aalborg University (as outlined in Section 7.2) were repeatedly noted by interviewees as exemplars in this area.

8.4. Risk of defaulting to the 'status quo'

While interviewees pointed to a range of ways that engineering education was likely to change in the coming years (as outlined in Chapters 6 and 7), many also cautioned that a positive sector-wide transformation was by no means inevitable. In the words of one vice dean:

> *"too many people are thinking that we won't go back [to pre-ET practices and priorities]. I'm sceptical about that... I think there is a 'ground state' and if we're not careful, there is too much of a temptation to fall back. Some energy is going to need to be put in there to ensure that we don't".*

While ET represented a time of unprecedented change across higher education, much of the reform was noted to be *reactionary ("everything has been done on the fly"*) and *temporary ("it is all quick and dirty solutions"*). As one dean noted, at the height of ET restrictions at their university:

> *"there is no intentionality... we are rolling with the punches versus saying strategically 'this is what we should do'... The problem is that we think this is going to go away, this mentality of 'don't buy an umbrella because this rain is only for a short time'".*

It was therefore suggested that many of the potential benefits of practices adopted during ET have not been fully understood or realised. At the same time, the transition out of ET has been accompanied (for very good reason) with an *"overwhelming enthusiasm to get back to normal" by re-establishing "the socialisation, the comradery, the fun"* on campus. However, in this *"rush back to face-to-face teaching on campus"*, interviewees pointed to a risk that *"if we manage it poorly, we'll lose some of the gains [of ET] and it'll be harder to regain this"* in the years that follow.

Interviewees went on to suggest that there may only be a narrow window of time to enable evidence-based and long-term change before the sector *"moves comfortably back to their old ways of doing things"*. They pointed to three barriers were likely to work against the capacity for engineering schools and programmes to embed such rapid systemic reform:

- **exhaustion:** simply put, and as repeatedly noted throughout this report, instructors and university leaders are emerging from ET *"completely exhausted"*. Concerns were expressed about their capacity to participate in major educational change initiatives at a time when many are *"holding on, waiting for when we can take a breath and enjoy life again"*.
- **institutional inertia:** despite the experiences of ET, it was suggested that agile and bold systemic change *"is not something that universities are particularly good at"* at all levels of the institutional hierarchy. The tendency to default to the pre-ET 'status quo' was noted to be deeply embedded at an administrative level (*"we are still under the impression that we will come back to the way we were"*) and at an instructor level (*"there is still a strong desire to teach as they were taught"*) and would prove difficult to shift in *"the retreat to the security of the old system"*.
- **new pressures and priorities:** as it emerges from ET, the sector was noted to be entering a time of considerable flux, facing a range of challenges whose solution may be prioritised over efforts to enable educational reform: *"some universities have really struggled to recruit [students] and others have over-recruited... some are letting staff go... some [faculty] are making some life re-evaluation decisions and we stand to lose a lot of talent... there are a lot of different risks"*.

Despite these concerns, most interviewees struck a positive note in their assessment of the future of engineering education. They suggested, however, that success would rest upon the capacity of the sector to take an evidence-based and coordinated approach that drew on the lessons learnt from ET.

9. Concluding comments

ET represented a systemic shock to engineering education worldwide. It was unforeseen, rapid and upended priorities and practices that had been deeply embedded in engineering programmes for decades. Drawing on interviews with instructors, education experts, university leaders and students worldwide, the *Crisis and Catalyst* study sought to understand the impact of this sector-wide shock in two dimensions: firstly, on the experiences of the engineering education community during ET and their reflections on the lessons learnt; and secondly, on the direction of travel for the sector beyond ET, particularly for programmes at the cutting-edge of pedagogical practice.

The **first part of the report** explored interviewees' experiences of and reflections on ET. The most consistent topic of feedback related to the concerns and challenges faced during this destabilising period. For example, interviewees pointed to ways that ET had both exposed and exacerbated many of the inequalities faced by the engineering education community. Of particular concern was how students without a dedicated place to work, reliable internet connectivity, and a smart device were denied access to much of the learning opportunities and communities of support available to their peers. Student and instructor mental health was also a major concern. The increased workload, social isolation, and uncertainty – that undermined autonomy and capacity to plan for the future – all took a heavy toll on mental wellbeing.

At the same time – and while acknowledging the shadow cast by these unprecedented challenges – interviewees went on to highlight new opportunities in engineering education opened up by ET. It was noted to be a time when a range of informal partnerships and communities of support were forged and strengthened. For many universities and instructors, ET was also a time of considerable educational experimentation and innovation, particularly as they sought to address student isolation, overwork, and wellbeing.

The **second part of the report** lays out interviewees' hopes, expectations and concerns for the engineering education sector as it transitions beyond ET. Most anticipated far-reaching changes to priorities, practices and cultures across the sector. Their reflections on the sustained and positive influence of ET on best practices in engineering education pointed to how ET had both precipitated new directions and accelerated existing trends:

- **precipitating new directions:** by catalysing new priorities and practices that may never have emerged but for the systemic shock of ET. These new directions for engineering education included, for example, a step-change to assessment processes, and a new role to be played by the academic community and pedagogical experts in educational strategy development.
- **accelerating trends in train:** an acceleration and validation of educational changes already under discussion or implementation prior to 2020. The 2018 MIT report[1] identified several defining features that marked out 'emerging leaders' in engineering education, such as the establishment of flexible learning pathways and the development of curricula that blend on-campus experiential learning with asynchronous self-directed learning. For leading engineering schools and universities, ET provided an opportunity to 'stress test' or 'scale up' these practices and the infrastructure needed to support them.

Interviewee feedback make clear, however, that these changes are likely to be confined to particular schools and universities: specifically, well-resourced universities already operating at the cutting-edge of engineering education and/or those that took an agile and community-led approach to navigating

ET. Interviewees based outside such institutions often had a much more pessimistic view of their institution's capacity to drive positive change or to engage instructors to support such efforts.

Overall, interviewees pointed to a range of challenges facing engineering education post-ET. Two themes threaded through many of the interviewees' concerns. The **first** is a stratification of the sector. Interviewee feedback highlighted the risk of a growing divide between *"the haves and have-nots"* in global engineering education, with widening inequalities between institutions and within the student communities they serve. The **second** is a concern that some institutions and programmes will emerge from ET with a culture in which students – their learning, advancement and wellbeing – are not a central priority. Without a clear set of educational values underpinning the use of digital learning, deep concerns were voiced about the proliferation of such forms of online learning and the impact this might have on students' learning, mental wellbeing and communities of support.

Despite these concerns, interviewee feedback made clear that the engineering education sector has entered a period of far-reaching change with the potential to enable a profound and positive transformation of the learning experience of engineering students worldwide. The consensus view was that, while ET has undoubtedly been a period of **crisis** – placing unprecedented demands on the sector and testing its adaptive capacity – it will also act as a **catalyst** for a new generation of leading engineering programmes in which the opportunities, learning and wellbeing of students are placed at the forefront. This can be seen most clearly in institutions such as Aalborg University (Denmark), Tec de Monterrey (Mexico) and ASU (US), for whom ET has been a springboard to catalyse and accelerate a suite of major educational changes. The sector, however, needs to move quickly to identify and embed good practices that emerged during ET. Engineering schools and universities must work together – across institutions and across countries – to sustain the drive for excellence in engineering education.

REPORT APPENDICES

Appendix A. Study methodology

One-to-one interviews were held between August 2020 and April 2022 with 226 individuals from 36 countries. This included consultations with 96 interviewees as part of the major case studies presented on the project website[3]. Interviewees represented a broad cross-section of the global engineering education community, selected from a range of grades, institution types, and geographic location. A breakdown of the interviewees by group is given in Table 3.

Interviewee group	Number of interviewees
Students (engineering undergraduates and recent graduates)	27
University leaders (presidents, vice-presidents for education, deans, vice-deans and department heads)	59
Instructors (faculty, lecturers, teaching assistants)	94
Educational specialists (educational developers, instructional designers, engineering education researchers etc.)	33
Others (partners from industry, the regional community or external educational support agencies)	13
TOTAL	**226**

Table 3. Interviewees consulted during the study by group

The first set of individuals invited for interview were those consulted as part of the 2018 MIT study on the global state of the art in engineering education[1]; the remaining interviewees were identified by fellow interviewees. A common set of questions was asked of all interviewees (as outlined in Table 4) with additional questions included for individuals with relevant specialist knowledge or experiences.

Interviews were typically one-to-one, of one hour in duration, and were conducted remotely by Zoom. Where requested, interview questions were supplied in advance. Two interviewees chose to respond to questions in writing and seven participated in their interview as part of a small group. Some individuals were interviewed on more than one occasion.

Quotes from the 226 interviewees are used throughout the report to illustrate the common views and themes that emerged.

The experience of emergency teaching

1. What would you identify as the major challenges faced by your engineering school/university during the period of 'emergency teaching' due to COVID-19? Are you aware of any effective strategies adopted to overcome any of these challenges?
2. What would you identify as the major milestones as your school/university navigated its way through emergency teaching? What were the key activities and priorities during each of these periods?
3. Is there anything that has surprised you about the challenges and opportunities faced in engineering teaching and learning during the period of emergency teaching?

Lessons learnt

1. What would you identify as the sector-wide lessons learnt from the adoption of online learning during emergency teaching in engineering?
2. What elements of engineering learning (if any) do you feel benefited from the shift online during emergency teaching?
3. Which elements of engineering learning have been particularly problematic to deliver online (if any) during emergency teaching? Were you aware of any effective strategies adopted to overcome these challenges?
4. What advice would you give to an instructor seeking to deliver engineering education activities fully or partially online in the future?

The long-term impact of COVID-19 and emergency teaching

5. How do you anticipate that pedagogies in engineering education might change (if at all) in the future as a result of the experience of COVID-19 and the period of emergency teaching?
6. Do you anticipate any other, wider changes to the engineering education sector as a result of COVID-19 and emergency teaching, for example to educational priorities, practices or educational cultures?
7. Do you see any risks or challenges facing the positive development of engineering education in the future as the sector moves beyond emergency teaching? If so, do you think that the sector is well placed to address these risks/challenges?

Table 4. Common questions asked to interviewees

Appendix B. List of case studies included in report

Co-funders

The research is co-funded by a consortium of universities and organisations with a particular interest in collaborative engineering learning and/or the use of educational technology in the engineering curriculum.

AALBORG UNIVERSITY DENMARK

EPFL

MIT School of Engineering

MIT MANAGEMENT SLOAN SCHOOL

NTNU Norwegian University of Science and Technology

Olin College of Engineering

PONTIFICIA UNIVERSIDAD CATÓLICA DE CHILE

Royal Academy of Engineering

SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN

Tecnológico de Monterrey

UCL

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