CEEDA case study report

Six case studies of the impact of COVID-19 on global practice in engineering education

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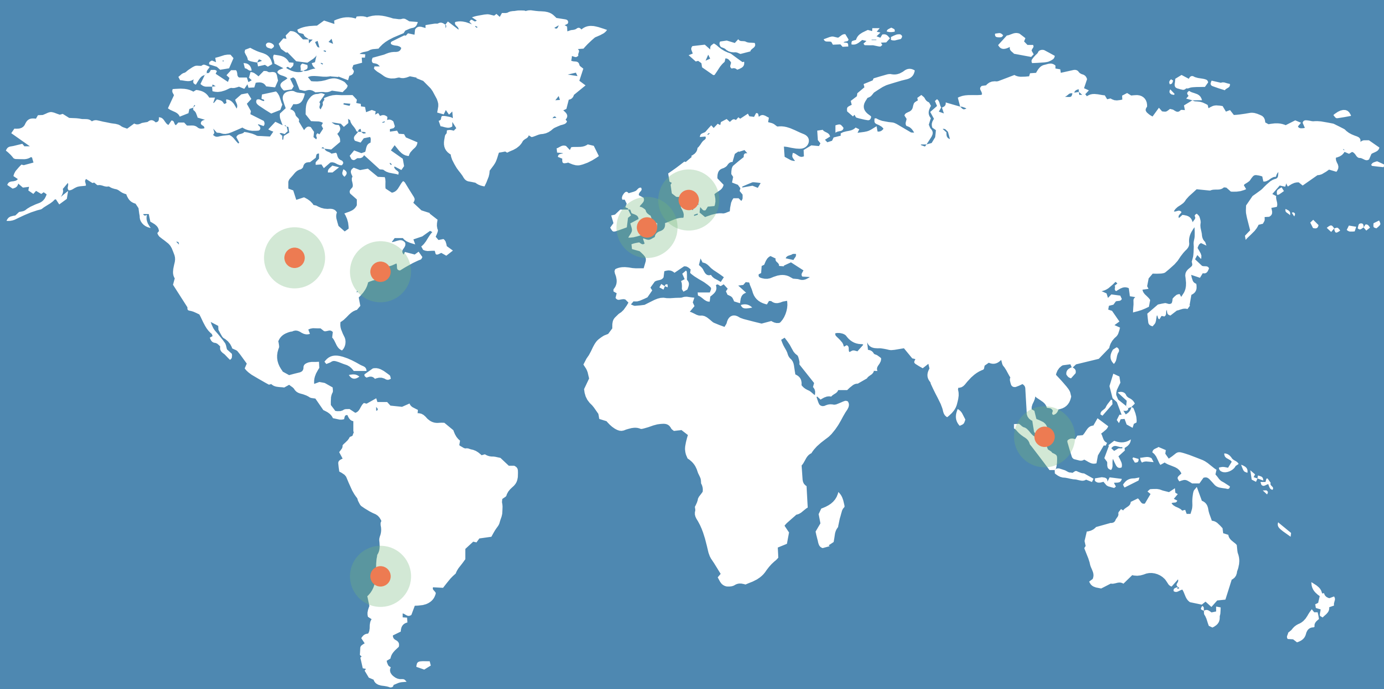
October 2022



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Contents

This report brings together examples of best practice in online engineering collaborative learning and examines the wider response to COVID-19 emergency teaching at six universities:

Introduction

The CEEDA (Collaborative Engineering Education in the Digital Age) study was commissioned to assess the impact of COVID-19 'emergency teaching' on the engineering education sector. The study was designed around two outputs, both of which are open source. The **first** output is the 'Crisis and Catalyst' report, which explores feedback from across the global engineering education community on the experience of emergency teaching and how it might impact the future trajectory of the sector. The **second** output is a series of in-depth case studies which explore the institutional response to emergency teaching at six of the universities identified in the 2018 MIT report[1] as 'emerging leaders' in engineering education. This report presents these six case studies.

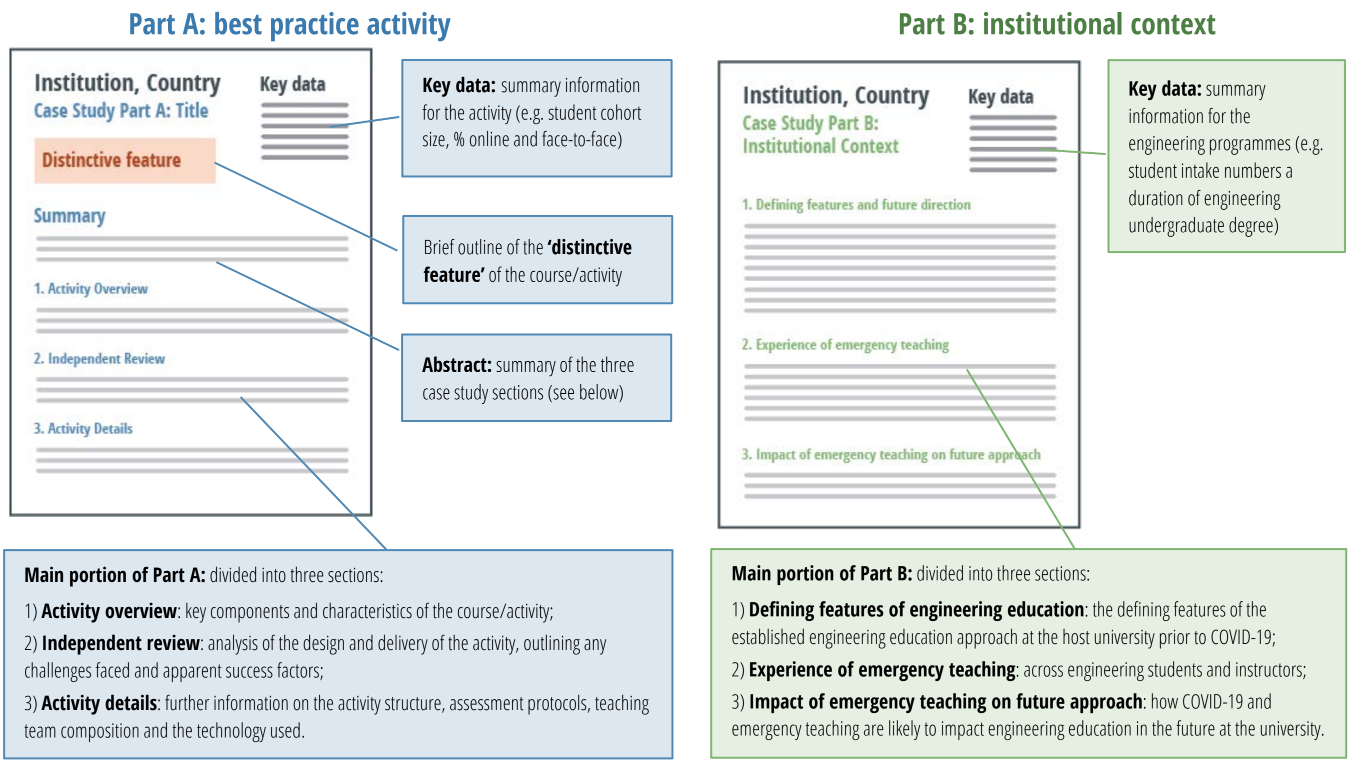
Case studies were developed independently by the CEEDA project lead, and were built from one-to-one semi-structured interviews with key stakeholders. Interviewees included those engaged in delivering both the case study activity/course under consideration and the institution's wider engineering education provision: faculty, university/school leaders, teaching assistants, students, recent graduates and external collaborators. Universities received drafts of the case study for review and approval.

Each case study is divided into two parts:

Part A. Best practice activity: a review and profile of an activity that exemplifies best institutional practice in online collaborative learning that was delivered during emergency teaching;

Part B. Institutional context: review of the institutional response to emergency teaching and how COVID-19 is set to influence the future approach in engineering education.

Part A and Part B of each case study follow a common structure, as illustrated below. Case studies are also available at the project website[2], which include videos outlining some of the key themes highlighted. The website also includes further background information about the study as well as the final report.



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

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

Iron Range Engineering, US

Case Study Part A – Best Practice Activity

Design project

Student cohort:	**150**
Location:	**100% online**
Duration:	**1 semester (16 weeks)**
Date delivered:	**Jan – May 2021**
Activity type:	**Team project**
New/existing:	**Existing**
Hands-on:	**Prototyping + experiments**
Cross time-zones:	**In some projects**

Distinctive feature of case study

Building motivation and self-directed learning through design projects that connect learning across the curriculum

Abstract

Activity overview

Each semester of Iron Range Engineering's two bachelor-level programmes are structured around a 16-week design project; students engage in these projects from programme entry and throughout their studies. These projects tackle open-ended challenges set by external clients that address a real industry or societal need. Projects are undertaken in one of two modes: 'campus-based' (prior to emergency teaching, students worked in teams with peers on campus) and 'work-based' (projects are embedded in paid work placements taken by students in companies across the US).

Independent review

The most striking feature of the Iron Range design projects is their curricular integration. The projects act as a hub that feed into and draw upon students' learning across almost all other components of the programmes. The success of the design projects turn, in part, on students' capacity to establish a close collaboration with team-mates and to immerse themselves in the context of the industry problem they are solving. Both elements were stress-tested by the introduction of emergency teaching in March 2020. However, the "*close-knit*" Iron Range community and one-to-one mentorship offered by instructors went a long way to offset the barriers introduced by the online pivot.

Activity details

Design projects typically follow a 'design sprint' structure: the 16-week projects are divided into three 'sprints' with teams expected to progress through an entire design cycle during each sprint. While teams are mentored by practicing engineers, students are expected to lead and manage all aspects of the project independently.

1. Activity overview

Based in rural Minnesota, Iron Range Engineering offers two programmes that culminate in a bachelor degree. Taken together, these two programmes[1] will be termed 'Iron Range' hereafter. Design projects – each 16 weeks in duration – are embedded in each semester of study in the Iron Range programmes, and form the spine around which the curriculum is built. The design projects take two broad forms which, prior to COVID-19 emergency teaching restrictions, were distinguished by their mode of delivery:

- **'campus-based' projects:** students tackle authentic problems posed by external (typically industry) clients, devoting around 10 hours per week to their project. Project teams are often vertically integrated, meaning that they bring together students from all semesters of study;
- **'work-based' projects:** working a 35–40 hour week on paid industry work placements, students form teams with their co-workers to tackle projects set by their employer. Most other curricular elements are delivered remotely (typically via asynchronously online learning).

During COVID-19 emergency teaching, however, both 'campus-based' and 'work-based' projects were predominantly delivered online. Three features set these Iron Range design projects apart from traditional engineering team-based projects:

- **they span the programme:** students engage in a range of design projects (taken from different sectors and perspectives) from matriculation and throughout their studies;
- **they are authentic:** project briefs are set by external clients to address a real industry or societal need. Students self-manage all aspects of the project independently;
- **they connect students' learning:** design projects draw upon and feed into almost every other component of the Iron Range curriculum (as discussed further in Section 2.1).

2. Independent review

2.1. Distinctive features

The most striking feature of the Iron Range design projects is their integration with the rest of the curriculum. As illustrated in Figure 1, the Iron Range curriculum is divided into three, roughly equal threads: technical, design and professional. The design projects act as a hub that connects and integrates students' learning across all three threads of the programme. The connections between the projects and the wider curriculum take two major forms, as described below.

Some of these connections to the design project are **written into the curriculum**. For example, as part of each semester's 'design workshops', students typically deliver six technical papers, all in journal article format. Most of these papers relate to students' design projects and explore the particular

[1] Further information on the structure and operation of these two programmes is given in Section 3.8.

design processes that they or their company have adopted. In a second example, students are asked to reflect on their learning and development each week within a 'learning journal'. The prompts given for student self-reflection often relate to particular experiences in their design project.

Other connections to the design project are **identified and shaped by students themselves**. For example, half of the technical thread is devoted to 'student-led advanced' (SLA) courses in which each student must identify the topic they wish to learn and (in most cases) design their own syllabus and assessment protocols to achieve this goal (under the guidance of an instructor). Students typically use SLA courses as an opportunity to master key concepts associated with their design project to help them improve or advance their ideas. In addition, 'deep learning activities' (DLAs) are embedded into all technical courses, and require students to undertake an experiment to explore one aspect of the course in more depth. Students often use DLAs to investigate key questions related to their design project. For example, one student interviewee, who was engaged on a water treatment project with a civil engineering consultancy firm in the Spring of 2021, designed an SLA competency in pump optimisation. For the linked DLA, he planned to collect and analyse data from a pumping station at his host company to evaluate the systems performance and offer recommendations for optimisation.

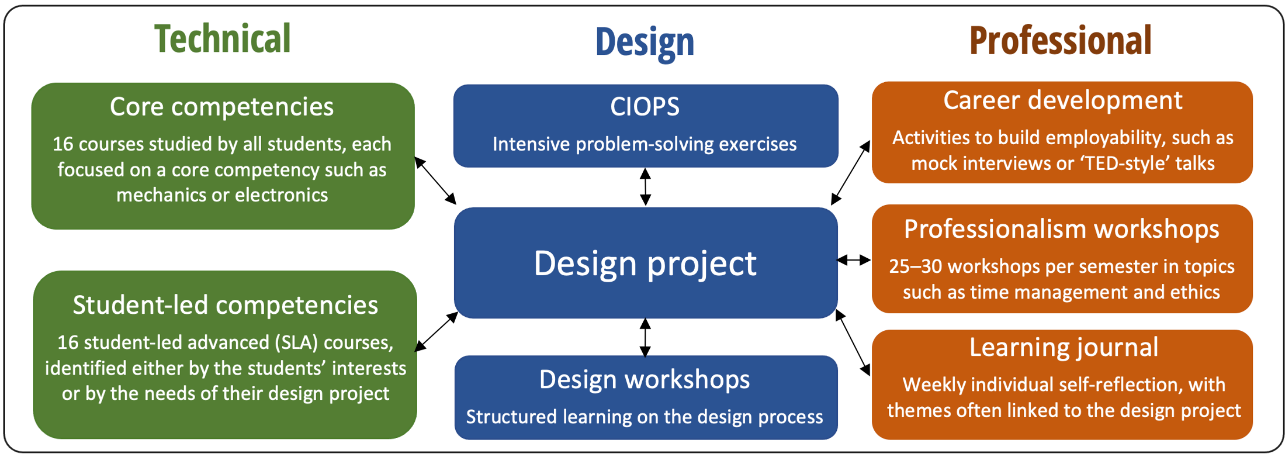


Figure 1. Connectivity apparent between the design project and all other elements of the Iron Range curriculum

As well as offering a mechanism for students to apply, synthesise, and contextualise their learning, the cross-curricular connectivity of the design projects also advances many of the core principles that lie at the heart of the Iron Range approach. For example, it provides a platform to further **autonomy and self-directed learning**. In particular, while the design project is a team-based activity, the components it connects to across the curriculum are typically undertaken individually. This provides a mechanism for each individual student to identify elements of their design project that they are of particular interest/relevance to them and build this learning in a way, and at a pace, that suits them best. The projects' curricular integration is also used to foster **intrinsic motivation** by establishing a driver for learning that is not based around academic grades, but instead rests on students' desire to produce the best possible showcase for their talents and achievements to prospective employers. With the design projects (and associated employability activities) touching almost every element of the curriculum, such triggers for intrinsic motivation are embedded programme-wide.

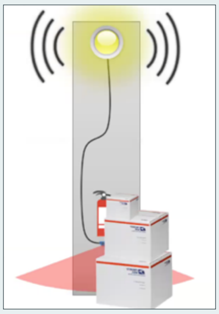
Student interview feedback pointed to the efficacy of this approach. When describing the synergy between her design project and self-designed SLA competency, one Iron Range alumnus noted:

> *"it really made the class much more real, like I've taken an [SLA] advanced hydraulics class, but then you're also designing a hydraulic system for a local mine, and you're presenting to very experienced engineers. That just creates a little more urgency: these are potential people that would hire you, so you also want to know what you're talking about… It's like almost like a pre-job interview*".

An illustration of the curricular connectivity of the Iron Range design projects is given in Box 1.

Box 1. Example of connectivity between the design project and the rest of the Iron Range curriculum

One interviewee for the case study was Kennedy St. John, a first-year student who had just completed a paid work placement at the United States Postal Service (USPS). As part of her placement, Kennedy was asked to design a system that triggered an alert if access to a fire extinguisher in a USPS facility was obstructed. Working with a USPS colleague over the course of a semester, she developed and validated a device to meet the brief, which she called the Obstruction Warning Light (OWL).



This design project drew upon and fed into Kennedy's learning across all three threads (technical, design and professional) of the curriculum, which included:

1. **technical:** Kennedy selected programming as one of her SLA competences and designed a syllabus to develop this competence, which she subsequently used to inform the programming of an Arduino device used during prototyping of the OWL;
2. **design:** during the one-week 'intensive problem-solving' activity, scheduled at the semester end, students were asked to identify an out-of-scope aspect of their design project to develop further. Kennedy chose to advance the design of the OWL to allow it to be reset and adjusted remotely. In addition, as part of the 'design workshops', Kennedy delivered a series of technical papers that reviewed the design processes adopted by USPS, such as their approach to iterative design.
3. **professional:** Kennedy delivered four separate presentations on the OWL project, each to a different audience. She noted how these repeated experiences, together with the support and feedback offered during professionalism workshops, helped to hone her public speaking skills.

The USPS is pursuing a patent for the OWL device, which is being deployed across its facilities nationwide.

2.2. Success factors

The Iron Range design projects are ill-defined and challenging by design. Taken from across a range of sectors and company profiles, these projects call upon students to assume the role of a professional engineer from entry to the programme and take a lead in managing all aspects of the project including liaison with the company client. Establishing the conditions for students to successfully navigate such projects is not straight-forward, particularly given that that the programmes' intake (of students from regional Community Colleges[1]) may have had no prior experience of student-led or project-based learning. Interview feedback suggested that four inter-related factors underpin Iron Range's success in fostering the competencies and conditions necessary for students to navigate these projects:

- **clarity of expectations and goals:** a range of mechanisms are put in place to make clear to students what is expected of them and why. While the design project briefs are open-ended, the expectations on teams are made explicit, both in terms of their professional approach and the deliverables required. Students also participate in 'learning to learn' courses which explore pedagogical theories and outline the evidence-based rationale for Iron Range's curricular design. Student interview feedback suggested that appreciating why they have been immersed in ill-defined or challenging project experiences has proved crucial to building their engagement and maintaining their focus on design projects, particularly during emergency teaching.
- **community of support:** one theme repeatedly highlighted by interviewees was the collegial "*close-knit*" community of support that extends across instructors and students in programmes. This culture was seen as an important counterbalance to the open-ended and complex nature of the design projects. In the words of one instructor, while the design projects are designed "*to put students in an uncomfortable position… there's a soft cushion landing for them, so it's not so risky for students to get out of their comfort zone*". The support offered is typically personalised and one-to-one, with regular and on-call mentorship offered throughout the programmes. Indeed, when asked to describe Iron Range as a whole, one student simply said: "*I would say it's very challenging and very supportive at the same time*".
- **iterative competency development:** as students progress through the Iron Range programmes, they are repeatedly exposed to a set of core concepts and experiences. A major focus of this 'triple helix' approach is to progressively build professional and employability competencies. Indeed, it is estimated that students will deliver around 100 presentations by the close of their Iron Range education. A surprising number of student interviewees spoke about how these repeated experiences of delivering presentations and practice interviews – in conjunction with feedback provided by instructors and peers – had helped them to overcome a deeply-held anxiety about public speaking. During emergency teaching, this 'triple helix' approach appeared to play a crucial role in fostering students' confidence in liaising with, and presenting to, industry clients that they may have never met face-to-face.
- **responsive programme design:** the student voice has long played an important role in shaping the design of Iron Range curricular activities. Student feedback and preferences are often captured in real time to decide, for example, the structure of a class or the priority topics to be covered in a design workshop. This responsive approach – combined with the small size of the student cohort – proved particularly valuable during emergency teaching. Students reported how problems that they flagged up to instructors were rectified rapidly, and curricular elements were quickly adapted to better suit students' online working modes and conditions.

Underpinning each of these factors is a remarkable capacity and willingness to support ongoing educational experimentation and evidence-based change that spans both Iron Range programmes. Continuous curricular renewal – in response to pedagogical evidence, best practice examples from peer institutions, and feedback from external advisors, staff, students and alumni – is integral to the Iron

Range culture. Enabling such a unique experimental culture is undoubtedly supported by the fact that Iron Range is based on a stand-alone satellite campus, located 300 miles from the institution that credentials its programmes, Minnesota State University, Mankato[1]. As one Iron Range instructor commented: "*the mothership is a long way away... we are in our own separate place, just like a bubble – just us faculty, our industry partners, and the students together. We feel kind of allowed to try things, we just try to use evidence-based practices, see what happens and then iterate*".

2.3. Challenges faced

Interview feedback pointed to a number of challenges associated with the design projects during emergency teaching conditions. While fears that multiple companies might 'lay off' work placement students after the pandemic first hit were not realised, two particular challenges remained.

The **first challenge** was distinct to the 'campus-based' design projects and concerned students' capacity to collaborate on projects and engage informally when working online. Prior to emergency teaching, each 'campus-based' design project team was allocated a dedicated room to use for the duration of the 16-week project. Interview feedback suggested that the Iron Range culture of peer support and collaboration was rooted within these spaces, fostering "*a very organic way of problem-solving*" with students working together on personal interest projects and assignments as well as their design projects. Following the online pivot, the loss of the project rooms was felt particularly strongly. Interviewees reported that students often struggled to "*reach out to one another*" in their design project teams and many of the "*informal conversations you have in the project* room" were lost.

The **second major challenge** facing the design projects during emergency teaching was students' lack of exposure to the industry context. Prior to March 2020, the face-to-face relationships established with industry clients and opportunities to physically explore the host company played a crucial role in shaping teams' conception of their project brief: "*students would go on site, see the facility, take measurements of where the problem is happening... get to know the client and ask them a lot of questions*". Even before the introduction of emergency teaching, a challenge consistently faced by teams was to "*get all the information you think you need [from the industry client] to address the problem... and know what questions to ask*" to ensure that they understood the project needs and constraints. This challenge was exacerbated after March 2020. Many teams were unable to meet their industry client, see equipment/facilities in person or collect on-site data relating their project brief: "*to get a hands-on feel for what's going on... something for their brains to picture when they're working on the project*".

Taken together, these two challenges affected teams' time management and progress on their projects. Interview feedback suggested that "*the projects essentially didn't get as far as they would have normally*", with students investing disproportionate time on background research at the expense of ideas generation and design development. The inability of many teams to produce physical prototypes during emergency teaching was noted to "*make it harder to produce something that feels valuable*" and appeared to further inhibit students' confidence and progress.

Two broad strategies were employed by Iron Range instructors to address these challenges. The first was to offer more explicit and targeted feedback during regular design review meetings to help teams identify and remove blockages to project progress. The second was to call upon students "*to be more intentional with their interactions*". In their communications with industry clients, teams were encouraged "*to be more persistent*" when requesting information and data, with a greater reliance on clear written communication and more frequent contact. Instructors also suggested that teams use video conferencing as a proxy for in-person collaboration in project team rooms: "*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*". Although experiences by teams varied, this approach clearly helped many students to foster ongoing informal collaboration and connectivity. As one noted, "*once you get over the weirdness of it, it was nice to see each other, even if no one was talking, just to know they were there*".

3. Activity details

This section provides further details about the Iron Range design projects. Specific information on the two programmes in which the design projects are embedded – including the structure, operation and focus of the programmes – is provided in at the end of this section (in Section 3.8).

3.1. Participants and project groups

All Iron Range students participate in one design project each semester. In the spring semester (January to May) 2021, approximately 150 students took part in a design project.

As noted in Section 1 (Activity Overview), Iron Range design projects take two forms: 'campus-based' and work-based'. Students engaged in **'campus-based' projects** work in teams of between four and six. Team members select and agree their individual team roles, which often include team leader, project manager and one individual focused on 'team morale'. Students engaged in **'work-based' projects** form their design project teams with co-workers from their host company.

3.2. Challenge/project brief

For the 'campus-based' design projects, prospective project briefs are prepared in advance by Iron Range project coordinators in collaboration with industry partners. Prior to the start of the semester, students are asked to select their preferred project options. It is recommended that industry clients propose 'back burner' projects for these briefs: ones which are of interest to the company, but not business critical. In the spring semester of 2021, these briefs included projects: to develop a filtration system that produces drinking water with minimal energy usage; and to design a 'universal ladder step' that can be used across a range of different agricultural vehicles to provide driver access. Students also have the option to establish an independent team-based project, either to enter an engineering design competition (such as the Baja SAE[2] competition) or to pursue their own entrepreneurial idea. Examples of such student-led entrepreneurial projects undertaken in the spring of 2021 included: one to develop a technical and business framework for the use of virtual reality in engineering education; and one to examine the feasibility of a renewable energy pump storage hydropower system.

For the 'work-based' design projects, students are expected to identify prospective employers and prepare applications for their work placements entirely independently. The design project is one component of the work that student conduct while on their work placement. The scope and focus of the design project will be first discussed by the student and their employer, and later agreed with the student's Iron Range facilitator. Examples of 'work-based' design projects undertaken by Iron Range students in the Spring of 2021 included: one to redesign a 'tumbler' for rotating foodstuff in a food processing plant; and one to support an upgrade to an energy substation in a regional city authority.

3.3. Structure of the activity

The structure of the 16-week design projects is not fixed: it varies between the 'campus-based' and 'work-based' projects and is adjusted semester-by-semester. However, the core components of the design projects delivered in the spring semester of 2021 are summarised in the table below.

Agreement of scope	At the launch of the 16-week project, teams/students met with their client to explore the problem and agree the scope for their design project. Teams/students then put together a 'scoping document' to lay out the expectations and responsibilities of both the team/student and industry client, which both parties signed. Agreement was also reached over the team roles to be taken by each student and the ongoing mode/frequency of communication with the industry client.
Design sprints	The rest of the 16-week project was divided into three 'design sprints', each of 4–7 weeks in duration. Following the Agile management approach, each 'sprint' involved one complete cycle of the design process, from problem definition through to evaluation of a selected idea[3]. With each subsequent sprint, teams/students iteratively built upon and refined their ideas. This 'design sprint' model was adopted as a mechanism to help students structure the project and ensure that momentum was maintained throughout the 16-week activity, particularly during the early weeks.
Design evaluation	Each 'design sprint' culminated in a report to the industry client and a 45-minute 'design review' oral presentation to an expert panel where students described the work delivered and reflected upon their learning (see Section 3.5 for more information about project assessment). At the close of Sprints 1 and 2, the design review panel provided feedback to the teams/students about their expectations for the next sprint.

[2] Baja SAE: https://www.bajasae.net
[3] Students were asked to structure the design process according to the eight elements steps of the 'design wheel': problem definition; design objectives; learning objectives; planning; team monitoring; ideas generation and selection; modelling and testing; and design evaluation.

3.4. Learning goals/objectives

The overarching learning outcomes for the design projects are the 'student outcomes' stipulated by the Accreditation Board for Engineering and Technology (ABET) for engineering programme accreditation[4].

In addition, each student is asked to identify their own set of 'individual learning goals' that are tailored to the needs and focus of their design project. These are checked and agreed by their facilitator in the early weeks of their project. Examples of these 'individual learning goals' devised by Iron Range students for their spring 2021 design projects included:

- *"to learn how a professional design process takes place and where I best fit into it"*
- *"to get a better understanding of how bearings function and how they are used/tested in industry"*
- *"to provide the best possible product, and to exceed expectations".*

3.5. Assessment.

A typical summative assessment protocol for the Iron Range design projects is outlined below, along with an indication of the proportion of the marks allocated to each core component.

1. **Project poster and engagement:** the quality of the poster outlining the project brief and the students' participation in the design workshops**.** *Graded by the design instructor.*	17.5%
2. **Design documents:** as part of their 'design workshops', students are asked to prepare six design papers each semester, all of which must adhere to a technical journal style. Four of these papers are directly linked to their design project (including a final paper on how the project was planned and executed) and grades for these papers count towards the design project score. *Graded by the facilitator.*	27.5%
3. **Individual contribution:** for 'campus-based' projects, the contribution of each individual student is evaluated at the end of each sprint via: peer assessment (captured through anonymised team surveys); an assessment by the team facilitator; and an 'individual contribution memo' produced by each student.	20%
4. **Scoping document:** at the semester launch, a document is compiled by each team/student to agree the project scope, focus and roles. *Graded by the facilitator.*	2.5%
5. **Design review:** 45-minute oral presentations delivered to a design review panel at the end of each sprint. *Graded by the design review panel.*	20%
6. **Final deliverables:** the project solution, as evidenced by drawings, prototypes and a technical report. The report is developed iteratively over the three 'design sprints'. Included in this report is a 'learning document' where students reflect on their learning throughout the project and the extent to which they have achieved the goals that they set themselves at the project's launch. *Graded by the facilitator.*	12.5%

[4] ABET: Criteria for Accrediting Engineering Programs, 2020 – 2021: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2020-2021/

It should be noted that items 1, 2 and 3 in the table above are assessed individually, while items 4, 5 and 6 are assessed across the team. The technical report is also sent to the industry client at the end of each sprint.

3.6. The teaching team

The teaching team supporting the delivery of the design projects includes almost all Iron Range instructors (which comprises 11 PhD professors and 12 professional engineering facilitators):

- **project coordinators:** four Iron Range professors oversee and manage the design projects. These roles include, for example: supporting facilitators and meeting with them on a weekly basis to coordinate activities and track progress; working with industry clients to identify suitable project briefs (in the case of 'campus based' projects) and liaising with employers to ensure that students are engaged on engineering appropriate tasks (in the case of 'work-based' projects).
- **team facilitators:** who provide mentorship to teams (in the case of 'campus-based' projects) or students (in the case of 'work-based' projects), meeting with them regularly throughout the semester. Facilitators typically have a background in professional engineering and are hired as adjunct professors specifically to fulfil this project role. Facilitators meet on a weekly basis with the program director, "*to calibrate and align what we're doing this week*".
- **industry clients:** one or two industry clients oversee and support each design project. The frequency and nature of meetings with the relevant students/team are agreed at the project launch.
- **design review panel:** this panel brings together Iron Range instructors and technical specialists with expertise relevant to the particular project. Design panels typically come together at the end of each 'design sprint' to review the project's progress and the students' learning on the basis of their oral presentation.

3.7. Technology used

Google Classroom and Google Docs were used to manage all course information and student/team submissions. Although no other technology was mandated, many students used Slack to communicate with team-mates and SolidWorks to model their design ideas. Many also used iPads and Apple Pencils, which were provided to all Iron Range students following the introduction of emergency teaching in March 2020.

3.8. Further details on the Iron Range programmes

Iron Range Engineering[5] offers two 'upper division' bachelor-level programmes: the Iron Range Engineering (**IRE**) programme and the Iron Range Engineering Bell (**Bell**) programme. Students joining both programmes have already completed their 'lower division' study – two foundational years in engineering higher education – at a Community College. IRE and Bell students graduate with an integrated Bachelor of Science, Engineering (BSE), accredited by Minnesota State University, Mankato.

The IRE programme is four semesters (two years) in duration and (pre COVID-19 emergency teaching) was delivered almost exclusively in person, on campus. The Bell programme is five semesters (two-and-a-half years) in duration and is primarily delivered online.

As detailed in this case study, the IRE and Bell programmes embed two types of design project: 'campus-based' projects and 'work-based' projects. A key distinction between the IRE and Bell programmes is the balance struck between these two project modes (see Figure 2). IRE students typically engage in 'campus-based' projects throughout their studies, although they can select a 'work-based' project in their final two semesters. Bell students take a 'campus-based' project in their first semester, followed by 'work-based' projects for the remainder of the programme. During emergency teaching, however, almost all elements of both programmes were delivered online.

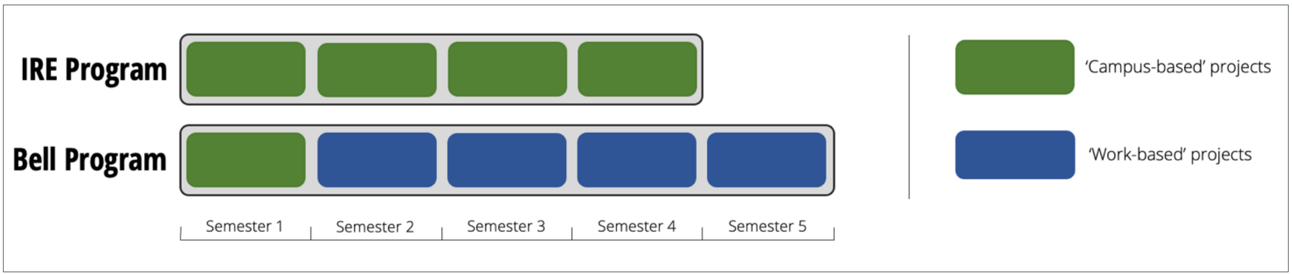


Figure 2. Typical structure of the four-semester IRE Program and five-semester Bell Program

Source of evidence

The case study for Iron Range Engineering (including Part A, this review of the Iron Range design projects, and Part B, a review of the 'institutional context' across the Iron Range programmes) drew upon one-to-one interviews with 16 individuals. The interviewees included: the directors of the two Iron Range programmes; two industry representatives who have acted as 'clients' for Iron Range design projects; one Iron Range alumnus; one Iron Range design project team facilitator; four Iron Range instructors; and six Iron Range students.

Further information about the methodology for development of CEEDA case studies is given at the project website[6].

[5] Iron Range Engineering: https://www.ire.minnstate.edu
[6] CEEDA case study structure and approach: https://www.ceeda.org/about#case-studies

Iron Range Engineering, US

Case Study Part B – Institutional context

Student intake to both Iron Range programmes (2020/21):	**≈ 70**
Number faculty/instructors (across both programmes):	**23**
Duration of undergraduate engineering degree (to BSE):	**2/2.5 years**

1. Defining features of the Iron Range Engineering education

Iron Range Engineering provides a bachelor-level education for students who have already completed two foundational years of higher education engineering study (typically in a 'Community College' setting). Iron Range offers two such 'upper division' programmes, both in integrated engineering and both credentialed by Minnesota State University, Mankato (through Bachelor of Science in Engineering degrees).

The first programme – the **Iron Range Engineering** (IRE) programme – was founded in 2009. It is a two-year (four semester) programme, with each semester structured around a 16-week team project. The student intake for the programme is small, currently 25 students per semester, and drawn largely from IRE's home state of Minnesota. An opportunity was identified, however, to 'scale up' intake numbers by applying the IRE model to a programme delivered predominantly online – in parallel with work-based learning experiences – that could be accessed by students from across the US.

This second programme – the **Iron Range Engineering Bell** (Bell) programme – was founded in 2019. It is a two-and-a-half year (five semester) programme. Prior to COVID-19 restrictions, the first semester (termed the 'Bell Academy') was delivered in-person on the Iron Range campus in Minnesota. For each of the remaining four semesters, students are employed in paid work placements (typically in their home region) and access the majority of their education remotely, predominantly via asynchronous online learning. Students are recruited to the Bell programme from across the US, with their tuition costs offset by the salary they receive during their four semesters on work placement.

Despite their difference in delivery method (predominantly face-to-face vs predominantly online) and student intake pool (state-wide vs country-wide), the two programmes are informed by the same project-led and self-directed educational approach. Both programmes also share a common curricular structure, as illustrated in Figure 1, that brings together three core threads:

- **technical:** students study 32 technical courses in all, of which half are core competencies (such as fluids or digital logics) and half are student-led advanced (SLA) competencies (which are identified by students, based on their personal interest or the needs of their design project);
- **design:** each semester, students engage in a new team-based design project, which forms the spine around which the curriculum is built. These projects are complemented by a series of intensive problem-solving exercises and workshops to build students' design capabilities;
- **professional:** students engage in a suite of activities to build their professional capabilities and employability, supported by guided self-reflection.

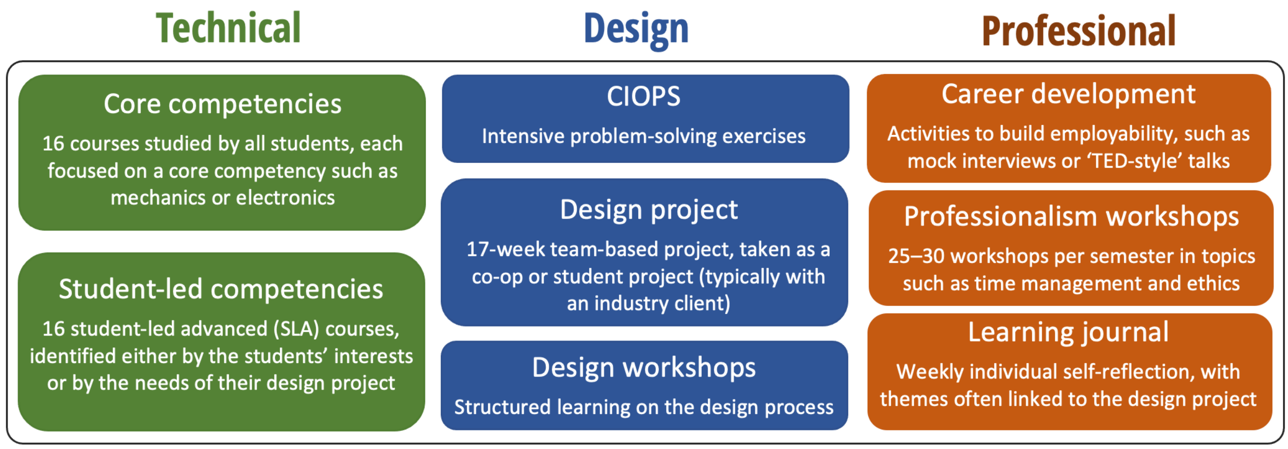


Figure 1. Curricular structure of the IRE programme and Bell programme

In addition to a common curricular structure, the two programmes also share a number of features that set them apart from peer engineering programmes. Four were repeatedly noted by interviewees:

- **project-based learning:** inspired by the Aalborg University model[1], IRE and Bell students engage in immersive team projects – delivered to an external client – from programme entry and throughout their studies. Most other curricular elements are linked to these semester-long projects, offering many opportunities for students to connect, apply and deepen their learning.
- **community of support:** IRE and Bell student interviewees spoke at length about the distinctive culture of mutual respect, trust and peer support brokered across the community of students, alumni and instructors. Students described how it was built on "*the deep personal connection*" fostered between students and instructors, and an expectation that students adhere to a code of professional conduct and communication throughout the programmes.
- **professional engineering emphasis:** a major focus for both programmes is developing students' professional engineering capabilities and employability skills. Students dedicate up to 10 hours per week to the development of their professional competencies (in areas such as ethical responsibility and technical writing) and their employability (through activities such as practice interviews and resume development) throughout their studies. Self-reflection is also an important focus, with students engaging in around 150 self-reflection exercises each year.
- **self-directed learning:** self-determination theory[2] is central to the IRE/Bell approach and is utilised to foster engagement and capacity for life-long learning. The emphasis on student autonomy and self-directed learning is particularly prominent. For example, in the majority of SLA courses, students not only identify the topic they wish to study, but also take the lead in writing the syllabus, identifying the key principles they must master, and devising the assessment protocol (subject to guidance and approval by a faculty member). In a second example, a course in 'learning to learn' is embedded throughout both programmes which, in the words of one interviewee, "*helps students to reflect on their learning and understand the meaning and the structure of what they're doing... and understand and practise how they learn best*".

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

[2] Self-determination theory (as defined by Edward Deci and Richard Ryan) proposes that three factors – autonomy, competence and relatedness – facilitate intrinsic motivation and growth.

One additional distinctive feature of IRE/Bell connects many of those listed above: continuous improvement. Both programmes take an evidence-based approach, drawing on pedagogical research, global best practice and ongoing stakeholder feedback. One consequence of this approach is the adoption of non-traditional pedagogies and practices throughout the programmes, such as the use of oral exams for assessing technical courses. Another consequence is that the programmes are constantly changing and updating. While key founding principles (listed above) and the overarching structure (illustrated in Future 1) have remained constant, it is estimated that around 10% of the curriculum changes each year. The scale of this ongoing change was apparent in the interviewee feedback, and is one in which instructors and students alike clearly play an active role.

2. Iron Range's experience of emergency teaching

2.1. Emergency teaching restrictions

Throughout the COVID-19 pandemic, the IRE and Bell programmes followed the emergency teaching restrictions set out by the Minnesota state government. The spring vacation in March 2020 was extended to three weeks to prepare for a fully online return for the final five weeks of the semester.

During the early weeks of the fall 2020 semester, some curricular components in the IRE programme were offered in hybrid form, with students given the option to participate online or in person. However, after a few weeks, the programme defaulted to a fully online mode, which remained in place until the end of the academic year in May 2021. For the 2021/22 academic year, it is anticipated that both the IRE and Bell programmes will be delivered in hybrid form.

2.2. Managing the transition to emergency teaching

The IRE and Bell programmes both operate on a semester-long (rather than year-long) intake cycle: a new cohort of students joins the programmes each semester, twice per year. The Bell programme was launched in August 2019, but a decision was made that enrolment for the second cohort would be postponed until August 2020 to allow time and space for student feedback and programmatic improvement during the programme's crucial first year. This decision proved prescient. When emergency teaching conditions were introduced, therefore, the Bell programme was only supporting a single student cohort, whose first semester had been spent learning face-to-face as part of the Bell Academy and who were already acclimatised to studying remotely while on paid work placements.

Both the IRE and Bell programmes also clearly benefitted from the expertise of Bell instructors, who had devoted much of the previous two years to developing and incrementally improving active, project-based online learning experiences. Much of the three-week break taken in March 2020 was therefore dedicated to discussing and sharing these experiences with IRE instructors and the regional Community College network. This included a series of workshops, delivered by the Bell programme director, on fostering student engagement and active learning in an online setting.

An early focus of attention was to ensure that students had the tools they needed to access their education remotely. For example, all IRE and Bell students were provided with an iPad and Apple Pencil, and instructors prepared and shipped out kits of parts to allow students to conduct lab-based or hands-on courses from home. Another priority was to simplify and signpost the curriculum in a way that helped students to manage their workload and priorities. As one IRE instructor put it, "*give them some rungs on the ladder to hang on to as they tried to climb that wall*". For example, some elements of the IRE curriculum were switched from concurrent to sequential delivery to simplify the learning experience and reduce the number of tasks that students had to manage at any one time. In addition, new systems were established via Google Classrooms to allow students to access their learning, track their progress and submit course deliverables online.

One unexpected barrier faced was students' unease about remote learning and their expectation that it would inevitably lead to an inferior learning experience as compared to a face-to-face education. However, interview feedback from students and instructors alike suggested that not only were many of these fears unrealised, but that some aspects of online learning offered significant and unexpected benefits above the face-to-face experience. One was the increased pool of industry contacts, prospective employers and alumni from across the US who were willing and able to engage with IRE/Bell students as part of design projects, showcase events and recruitment activities. Another reported benefit was the increased flexibility offered by online interactions, allowing students to schedule meetings or engage in asynchronous learning from different locations and at different times of the day. Combined with the culture of personalised support and mentorship provided by the IRE/Bell programmes, this flexibility offered new opportunities for students to ask for and receive one-to-one online support on-demand from facilitators and instructors in a way that would not have been feasible in a face-to-face setting.

2.3. Addressing the challenges of emergency teaching

Interviewee feedback pointed to three major inter-related challenges faced by the IRE and Bell programmes during the period of emergency teaching, as outlined below.

The **first** challenge was student recruitment. Both IRE and Bell are new programmes with relatively small intake numbers. Their enrolment is heavily dependent on in-person recruitment events in Community Colleges, which are held across the state (for the IRE intake) and across the country (for the Bell intake). The high levels of engagement and interest typically generated at these face-to-face events was not replicated when recruitment activities moved online from March 2020. Anecdotal feedback also suggested that some negative experiences of online learning in the Community College setting may have deterred some prospective students from considering a predominantly online programme such as Bell for future study. Probably as a result of both of these factors, applications to join the IRE and Bell programmes dipped significantly for the January 2021 intake. It was noted, however, that application numbers for the August 2021 intake had "*bounced back*" and the Bell programme is on track to grow its annual student intake to 150 in the coming years.

The **second** challenge was particular to the Bell programme and concerned student disengagement. The first semester (the Bell Academy) is designed as an immersive face-to-face semester that introduces students to the programme ethos, approach and community. As a result of emergency teaching, the second student cohort (Cohort 2, that joined the programme in August 2020) participated in the Bell Academy almost exclusively online. It quickly became clear that Cohort 2 was demonstrating much lower levels of engagement that either their IRE peers[3] or the cohort that had joined the Bell programme the previous year. As the one Bell instructor noted: "*we had students not coming to class, which in IRE and Bell just doesn't happen, and many of them would have their cameras turned* off". Two strategies were employed to address this issue. Firstly, a six-week pre-enrolment orientation course was devised for Cohort 3 (enrolled in January 2021) to establish clear guidelines for the professionalism and self-directed learning expected of Bell students. Secondly, ten minutes were allocated each day in the Bell Academy schedule to a 'morning meeting' that brought students together to "*engage them, pump them up, run through the day and frame how these activities bring value to their career*". Taken together, these two interventions were described as "*game changers*" for improving engagement levels among Cohort 3: "*by setting a higher bar of expectation at the beginning and then having these regular meetings, we completely solved the engagement problem that COVID put on our doorsteps*". It was noted, however, that establishing high engagement levels in Cohort 3 proved easier than reversing the disengagement of Cohort 2: "*those who were disengaged, they're still disengaged. We can't re-grab them*".

The **third,** and perhaps most significant, challenge identified by interviewees was that of student mental health and social isolation from the IRE/Bell community while learning remotely. Many spoke about the "*family-like*" community of peer-support that spans the IRE and Bell programmes. Their feedback suggested that face-to-face interaction has historically played a major role in this community-building, with many recalling with fondness social events such as barbecues and camping trips that had brought together students, instructors, and alumni prior to March 2020. The loss of this face-to-face community was clearly keenly felt, and considerable effort has since been invested in finding new ways to connect students and staff remotely. Instructors worked to establish more frequent and regular contact with students: "*creating familiarity, showing compassion, and having that be a part of every day… using zoom to create that social connection that used to come from the unscheduled contact on campus*". A range of optional social activities was also organised to connect the community remotely, such as take-out meals ordered and delivered to students' homes during evening activities, and virtual walks where "*everybody would turn their cameras on, and we'd go on a walk, and talk through Zoom*". With many students presenting with potential symptoms of anxiety and depression, programme directors, instructors and project team facilitators have also paid particular attention to identifying at-risk students and directing them to professional support services. In addition, new activities were embedded into the professionalism workshops to support students' growth mindset and help foster resilience, mindfulness and well-being.

[3] Interviewee feedback suggested that similar problems were not experienced with incoming IRE students because most of this cohort had followed IRE's dedicated foundational ('lower division') programme prior to enrolment and so had already connected with the IRE community, culture and expectations. Feedback also suggested that the vertical integration of courses (in which students from all semesters of study work together) helped to infuse a culture of intrinsic motivation into the incoming cohorts.

3. Impact of emergency teaching on future aproach

Interview feedback suggested that the experience of emergency teaching is set to have a profound impact on the IRE/Bell programmes. In the words of one IRE instructor, "*we learned a bunch of new things [from emergency teaching] 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*".

Some of these impacts represent an acceleration to and validation of changes already planned prior to the online pivot. However, many are innovations inspired and informed by the experience of emergency teaching. For example, 'morning meetings' that frame the working day and build community will continue to punctuate Bell Academy's daily schedule. Similarly, the integration of activities to build resilience and well-being are also expected to become permanent elements of the IRE and Bell programmes. As the Bell director noted "*we hadn't talked about self-compassion prior to emergency teaching, but it's so important, not just during a pandemic, but in any part of engineering education and in practicing being an engineer... We're going to keep doing those workshops*". However, perhaps the most far-reaching impact of emergency teaching will be to increase the use of hybrid learning, as outlined below.

While the Bell programme was established to offer more flexible ways for students to learn, some limitations were imposed. For example, all students were required to travel to Minnesota to attend the first semester (Bell Academy) in person. It had been assumed that the professional capabilities and intrinsic motivation necessary to propel students through four semesters of remote learning (while on engaged on paid work placements) was best fostered via an intensive semester of face-to-face learning. However, in the words of the Bell programme director, the experience of emergency teaching demonstrated that "*you can have a very intense life-changing event from your bedroom... We've found a way to use technology to create social contact which is so important for [student] motivation*".

From August 2021, the Bell Academy will be offered as a hybrid experience, such that incoming students can opt to participate online or on campus, depending on their personal circumstances. It is anticipated that this flexibility will help to open up the programme to new pools of prospective students, particularly those who are based in what have been termed 'STEM deserts': areas of the US where no higher education opportunities currently exist in STEM (science, technology, engineering and mathematics). Similarly, plans are underway to offer selected IRE technical courses in hybrid mode, allowing students more flexibility to access this learning asynchronously, as and when needed. The limiting factor for these changes will be the programmes' ability to access technology for hybrid learning that is not prohibitively expensive and "*where folks in the physical environment and folks who are beaming in through a virtual environment are having roughly the same experience*". In the shorter term, while new technology is being developed and tested, the delivery of some 'hybrid' experiences involving group collaboration and/or hands-on learning will require the student cohort to be divided into two discrete streams – one for those engaging online and one for those engaging face-to-face. It is anticipated, however, that a truly integrated hybrid programme experience will be rolled out in the coming two years.

The changes outlined above will serve to reinforce and build upon the already striking focus on student autonomy and self-directed learning evident throughout the IRE and Bell programmes. They are also nurtured by the deeply-rooted IRE/Bell culture of educational experimentation and ongoing programmatic change, features that will undoubtedly continue to regenerate the priorities and approaches of both programmes for many years to come.

Source of evidence

The case study for Iron Range Engineering (including Part A, the review of the IRE/Bell design projects, and Part B, this review of the 'institutional context' across the IRE and Bell programmes) drew upon one-to-one interviews with 16 individuals. The interviewees included: the IRE programme director; the Bell programme director, two industry representatives who have acted as 'clients' for IRE/Bell design projects; one IRE alumnus; one IRE design project team facilitator; four IRE and/or Bell instructors; three IRE students; and three Bell students.

Further information about the methodology for development of CEEDA case studies is given at the project website[4].

[4] CEEDA case study structure and approach: https://www.ceeda.org/about#case-studies

UCL, UK

Case Study Part A – Best Practice Activity

Mathematical Modelling and Analysis

Student cohort: **1000**
Location: **100% online**
Duration: **10 weeks (of core teaching)**
Date delivered: **Oct 2020 – June 2021**
Activity type: **First-year core course**
New/existing: **Reformed course**
Hands-on element: **No**
Cross time-zones: **Yes**

Distinctive feature of case study

Building student engagement through the contextualisation of learning

Abstract

Activity overview

Mathematical Modelling and Analysis 1 (MMA1) is a first-year course that seeks to engage students with the applications of mathematics and equip them to use mathematical ideas and language to model authentic engineering and societal problems. Structured around a series of week-long scenarios, students are first introduced to a real-world challenge – such as climate change – before exploring the mathematical concepts that can be used to model it – in this case, differential equations.

Independent review

What sets MMA1 apart from peer courses worldwide is its success in setting mathematics in a relatable context where it can be used to model and explore students' observations of the real world. This contextualisation appeared instrumental to establishing the high levels of student engagement associated with the course.

Activity details

MMA1 is a foundational mathematics course taken by 1000 first-year engineering undergraduates. With active learning embedded into both the synchronous and asynchronous elements of the course, it brings together three elements: (i) Fundamentals (to support and consolidate students' understanding of the course's mathematical prerequisites); (ii) Core Topics (the major focus of the course, which introduces a new real-world scenario and mathematical concept each week); and (iii) Computational Modelling (in which students are asked to explore the scenario and mathematical topics using the programming language MATLAB).

1. Activity overview

Mathematical Modelling and Analysis 1 (MMA1) is a 10-week foundational mathematics course taken by almost all first-year undergraduates – totalling around 1000 in 2021/21 – in UCL's school of engineering (UCL Engineering). MMA1 seeks to engage students with the applications of mathematics and equip them to use mathematical ideas and language to model authentic engineering and societal problems.

In 2014, UCL Engineering launched the Integrated Engineering Programme (IEP), a radically redesigned undergraduate curriculum that emphasises multidisciplinary learning and the application of students' engineering learning to real-world problems. While the IEP prompted systemic changes to the first-year mathematics course, concerns remained about its excessive focus on abstract theoretical concepts (leaving some students unable "*to apply their mathematical knowledge in the third or fourth year*") and its fragmented approach (with instructors from different departments lecturing on a new topic each week with limited integration to connect students' learning). Calls for reform to this course grew over the seven years that followed. However, the logistical challenge of coordinating a common way forward across eight[1] separate departments stymied action. The move to emergency online teaching at UCL, however, offered an opportunity to consolidate and accelerate plans for fundamental change. In the words of the course lead: "*if we're going to take this online, we're going to do it as well as UCL possibly can… let's take the best out of a terrible situation and make something that we are proud of*".

What emerged was a root-and-branch reform to the course focus, structure and pedagogy. MMA1 is structured around 10 week-long scenarios. Each week, students are asked to "*start by observing the real world*" as they are introduced to a new authentic application – such as the economics of family-run coffee plantations in Brazil – before exploring the mathematical concepts that could be used to model and investigate it – in this case, calculus. The synergy between each application and associated concept is explored throughout the week, culminating in a group activity where students are asked to develop a mathematical model to describe the real-world scenario, such as air pollution or non-invasive surgery.

The course is structured around three components:

1. **Fundamentals:** an optional, self-paced component designed to ensure that students are equipped with the prerequisite mathematical capabilities to tackle the Core Topics;
2. **Core Topics:** the major focus of the course that explores a new mathematical concept each week, such as complex numbers or integration, together with a linked real-world 'scenario';
3. **Computational Modelling:** to support students' learning of the Core Topics, they are asked to model the mathematical concepts and scenarios using the programming language MATLAB.

Each week, a new 'scenario' and mathematical concept are threaded across each of these components and throughout the course's asynchronous and synchronous activities. This connectivity is designed to help students contextualise, explore and integrate their learning.

[1] Please note: UCL Engineering is home to 10 departments in all; students from eight departments participated in MMA1.

2. Independent review

2.1. Distinctive features

Although the look and feel of MMA1 is very different from a typical mathematics foundation course, what most sets it apart is its success in setting mathematics in an authentic and relatable context where it can be used to model and explore students' observations of the real world. The course lead is a driving force behind this approach. He explained how he had been influenced by his experience as a mathematics teacher to disadvantaged children in Brazil, where he had, in his own words:

> *"captured [children's] attention with mathematics by showing them that mathematics is a language that they can use… [to] take a look at the world around them and describe these physical phenomena with mathematical variables and operations, to make simple models… The connection needs to not only be intellectual, there needs to be a human connection"*.

This approach of asking students to build models that explain and explore "*problems related to humanity*" is infused throughout the course, with the complexity of challenges building progressively over the 10 weeks. There is, of course, a risk that such attempts to contextualise mathematical learning in real-world applications will introduce artificial constructs into a course that distract from students' learning rather than add to it. The question of whether these scenarios felt 'contrived' was therefore addressed explicitly during the interview process. Student feedback, however, was unequivocal and suggested that this approach was both "*genuinely interesting, genuinely fun*" and offered a platform to explore, apply and deepen their learning. Interviewee feedback from instructors similarly pointed to a clear link between high levels of student engagement and both the relatability and societal relevance of the 'scenarios' integrated into MMA1. In the words of one teaching team member:

> *"the students were really surprised, realising I can actually change things. You know, I can actually plan a protocol for a non-invasive surgery. I can design a microphone. I could help a farmer to maybe one day to get to more profit. It's really connecting science to the individual, making engineering more human and more personal… the students came in with a lot more excitement".*

Some interviewees also went on to suggest that the course had helped to broaden students' perceptions of mathematics from being a rigid method that only offered "*just one right answer*" to a tool that is used by engineers to investigate observed phenomena and explore new ideas, and where the solutions developed are open to discussion and debate. One student spoke about the realisation amongst his group of friends on the course that they had all taken strikingly different approaches to the same coursework problem: "*it was so different for everybody, but it was not wrong. You could see the logic, but it was amazing how we had used tools so differently on the same topic*".

2.2. Success factors

As noted in Section 2.1, a particularly striking theme of interviewee feedback was the perceived high levels of student engagement with the course. One departmental lead characterised this as, "*not just* *passive engagement, like going to lectures and waiting for things to happen, but an actual active engagement with the material*". Fostering such high levels of engagement was by no means guaranteed, particularly for a foundational mathematics course that brings together a large and diverse student cohort from across a range of disciplines. Indeed, the previous version of the course was long associated with poor student feedback and low engagement, and some in the teaching team feared that the fully online delivery in 2020/21 would only exacerbate the challenges faced. The "*overwhelmingly positive*" student response to MMA1 therefore came as something of a surprise to many. There appeared to be several factors underpinning high student engagement. Undoubtedly, the first was the contextualisation of students' learning in real problems, as described in Section 2.1. However, a number of other factors also appeared to be crucial, including the course offering:

- **a clear, coherent and active approach:** the course design, as delivered through the learning platform Moodle, was described as setting "*a benchmark for other courses*" in UCL Engineering. Structured week-by-week, the online information offered students clarity on the structure, focus and expectations of the course in a way that allowed them to plan their time and monitor their progress. Considerable expertise and care were also devoted to embedding active learning into both the synchronous and asynchronous components of the course and establishing a clear connection between each of these activities.
- **responsiveness to student feedback:** two mechanisms were established to provide appropriate and rapid feedback to students' questions while working asynchronously. Firstly, an automatic[2] marking system was established for MATLAB coursework that provides students with immediate feedback on their work, including explanations relating to common errors. Secondly, an online Moodle forum was established where post-graduate teaching assistants (PGTAs) provided rapid and detailed responses to questions posed by students throughout each week. Student feedback suggested that, although not all posted questions on the forum themselves, a large proportion regularly reviewed the threads of questions and responses.
- **small group learning:** despite the large cohort size (of around 1000 students), all synchronous workshops were based around learning in relatively small groups of 45–50. Students remained in the same departmentally-based group for all 'live' sessions throughout the course, in which they were able to build networks and friendships: "*it is a huge [course]… but they are not looking out at a sea of students… they are working with a small group of friends*".
- **engaging students from all backgrounds:** a major criticism of the previous mathematics course was that it did not "*provide a level playing field for students coming in from different backgrounds*". It neither offered support to students without the required prerequisite mathematics high school attainment (this learning was delivered through a separate 'remedial' mathematics programme) nor provided opportunities to extend the learning of students with a strong mathematical background. In contrast, interview feedback suggested that MMA1

[2] MATLAB Grader: https://uk.mathworks.com/products/matlab-grader.html

offered an enriching learning experience for students of all mathematical aptitudes, including those at either end of this distribution. The optional 'foundational' component supported students' self-paced learning in the key mathematical course prerequisites, without calling for them "*to identify themselves as needing extra help*" by signing up for 'remedial' sessions. The application of mathematics to model real societal and engineering problems, accompanied by training in MATLAB, was also understood to "*offer something completely new for the high achievers in mathematics*" to extend their learning.

- **avenues for collaboration**: MMA1 offered a number of different avenues for student-led learning and collaboration, such as via the online forum (to discuss and debate questions), the online 'share boards' (where students could share ideas and solutions asynchronously), and the group activities during the 'live' workshops (to develop and explore mathematical models).

While undoubtedly the product of committed collaboration of instructors from across UCL Engineering, the success of MMA1 in establishing each of these components was underpinned by two key factors.

The **first** was the coherence of vision adopted for the course, which was driven by two individuals: the course lead and the school's learning technologist. Each brought considerable pedagogical experience – both, interestingly, with backgrounds as high-school teachers – and were given the autonomy to design much of the course's structure and focus from a blank slate. A crucial outcome of this collaboration was the identification of 10 real-world applications that punctuated the course: to ensure that each of these scenarios offered an appropriate balance of societal relevance and applicability to the mathematical concept in question, while at the same time connecting with each of the eight engineering disciplines represented by MMA1 student participants. The "*active flipped learning*" approach taken by MMA1 – one that connects the synchronous and asynchronous learning through a real-world "*hook that engages the students' imagination"* – also drew upon a model that had previously been validated by the school's learning technologist within UCL's school of management[3].

The **second** success factor was the disruption imposed by emergency teaching. Not only did this provide the conditions for collective and abrupt change to the course, it also enabled access to additional resources for the transition to online learning, including the allocation of a significant number of additional PGTAs and dedicated support from the school's learning technologist. One interviewee described the development of MMA1 as the product of: *"a lot of personal and institutional investment by all concerned. It was the sort of investment departments and individual academics would not necessarily consider if there was no pandemic"*. The outcome, however, provides a clear demonstration of what can be achieved through a blended approach when a unified and coherent vision is applied and dedicated resources and expertise are made available. That the concept was proven in a course such as foundational mathematics – long associated in universities worldwide with logistical complexity and low student engagement – is likely to turn heads across the engineering education sector.

[3] Active Flipped Learning Overview: https://mediacentral.ucl.ac.uk/Play/26860

2.3. Challenges faced

Interview feedback suggested that MMA1 faced a number of challenges.

Some challenges were associated with the **design and development** of the course, and the logistics of coordinating an educational change that encompasses eight distinct departments during a global pandemic. The development of the virtual learning environment was non-trivial, and called on a significant investment of time and expertise by the school's learning technologist. In addition, some members of the teaching team initially expressed deep concerns about driving a change of such magnitude "*in a year when I am already anxious, when I want to hold onto things I know*". Considerable time was devoted to cross-departmental discussion, to build cohesion across the teaching team, explore the vision for the course and allay concerns that students would not engage with the scenarios or the asynchronous activities. This teaching team met regularly before and throughout the course to, in the words of one member, "*support each other and share best practice".* It was noted that, by the third or fourth week of delivery of the course, the teaching team had developed a high level of cohesion and trust, with some reporting feeling empowered "*to be more ambitious*" in workshops in their own departments based on the experiences of and approaches taken by others.

Interview feedback also pointed to a range of challenges associated with the **course delivery**, such as connecting students across different time zones for synchronous collaboration. However, the challenges repeatedly highlighted by interviewees related to fostering student connectivity and active interaction when learning exclusively online. For example, members of the teaching team pointed to the difficulties they had faced in identifying students "*that are struggling, but are not saying anything*" within an online environment. In the words of one PGTA:

> "*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 this year [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 his experience of productive, collaborative group working in most weeks when "*everyone was on camera*" with one particular week when he was allocated to a group where "*no one had their camera on, and no one spoke. We all just ended up working on our own in silence*". Interviewee feedback suggested that the "*student culture for having cameras switched on*" varied considerably by department. However, the number of MMA1 students opting to keep their cameras turned on during the synchronous workshop sessions reduced progressively throughout the 10-week course in almost all departments. This problem was replicated in courses throughout UCL Engineering (and, indeed, throughout other engineering schools worldwide) over the course of emergency teaching.

3. Activity details

MMA1 is a mandatory first-year course for UCL Engineering undergraduates, scheduled in the first term of study. It is a 15-credit course (out of 120 credits allocated to the full academic year), equating to 150 hours of learning over the full academic year (including assessments and exams in the second and third terms).

3.1. Participants and project groups

Around 1000 students participated in MMA1 in 2020/21. This cohort was divided into sections of 40–50 students, all from the same department, for all synchronous 'live' workshop activities. For group activities, each section was further divided into different groups each week, each of 5–6 students.

3.2. Structure of the activity

The 10-week course is structured around a new mathematical topic and connected real-world scenario each week. So, for example, in the fourth week of the course, complex numbers are explored in the context of microphone design; and in the seventh week, differential equations are used to study the energy balance model of climate change around the planet earth.

Within this week-by-week structure, the course brings together three components: Fundamentals, Core Topics and Computational Modelling. As illustrated in Figure 1, each component includes synchronous and asynchronous elements and is supported by an online Moodle 'forum' where students can post questions throughout the week (with responses provided by PGTAs and peer students). Further information about each component is summarised in the table below.

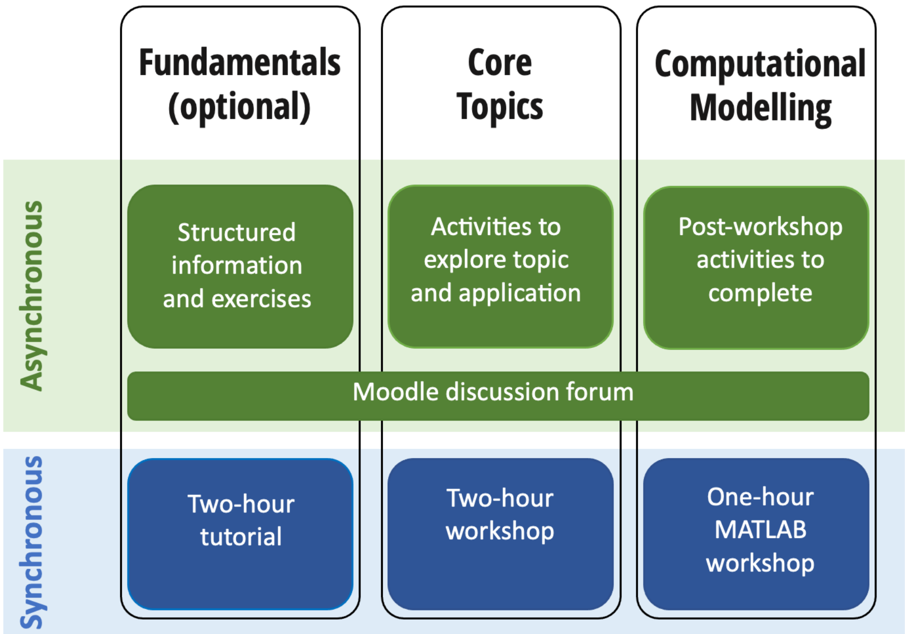

Figure 1. Three components of MMA1, each supported by synchronous and asynchronous activities

Fundamentals	This optional and self-paced component supports students' learning in the prerequisite mathematical concepts used in the course, and ensures that all students are able to engage fully with MMA1, regardless of their mathematic backgrounds. A 90-minute 'diagnostic test' at the beginning of the course allows students to self-assess their background mathematical knowledge and identify any particular areas of weaknesses. The Fundamentals component brings together preparatory information and exercises (delivered asynchronously) with a 'live' tutorial session to address specific questions students may have. Although the Fundamentals component of MMA1 is optional, over 50% of students opted to participate during the 2020/21 course.
Core Topics	Each week, students are introduced to the new application and mathematical topic through a series of asynchronous activities (such as videos, quizzes, polls and exercises) designed to take around three hours to complete. These, for example, might include a short video introducing the primary factors influencing climate change, or a request for students to post examples on a 'share board' of consumer products that utilise complex numbers in their design. The weekly two-hour 'live' workshops are designed to analyse and apply what students have learnt in the asynchronous activities. The departmental lead opens the workshop with a broad description of the mathematical topic and application, interspersed with outcomes from the online quizzes that students completed during their asynchronous learning to explore the ideas and discuss any common errors made. After working on some simple problems individually, students are then divided into groups of five or six to tackle a challenge that brings together their learning for the week (see Section 3.3 for examples).
Mathematical Modelling	Using the programming language MATLAB, this course component supports the development of students' programming and modelling skills. It is designed to help students visualise and model real-world problems. For example, one exercise was to predict the time it would take to clear a lake of water pollution. 'Live' workshops open with an introduction to a different feature of MATLAB each week. Students are then asked to apply these principles to a series of problems that are completed asynchronously, following completion of the workshop.

It should be noted that, once emergency teaching restrictions are lifted at UCL, it is envisaged that the two-hour synchronous 'core topics' workshop will be held face-to-face, but most other activities will continue to be delivered online.

3.3. The challenge brief

Each week of MMA1 culminates in a group activity that brings together a mathematical concept and real-world scenario. The table below provides examples of group activities taken from two particular weeks in the course: week 5, which focuses on **derivatives**, and week 6, which focuses on **integrals**.

Week 5	In week 5, the concept and application of **derivatives** are explored in the context of family-run agriculture in Brazil. The mathematical tools needed to describe and optimise systems that change as a function of one or several variables are taught using differential calculus. During the synchronous workshop, students are asked to design coffee plantation zones that maximise the farmed area while minimising the perimeter, such that small-scale family-based farmers can optimise their production. For the **group activity**, students are challenged to develop and explore a mathematical model that describes the profit made by a small coffee grower. Using the product price for two types of coffee (Arabica and Robusta) as working variables, a number of constraints for the problem are defined, such as production costs and a maximum joint production capacity for both species of coffee. Groups are asked to identify the optimal prices that should be charged by farmers that allow them to maximise their profits within the problem constraints.
Week 6	In week 6, students study the concept of **integrals** through investigating heat deposition in non-invasive surgery techniques like Laser or High Intensity Focused Ultrasound surgery. The fundamental theorem of calculus is explored through simple models of temperature change and heat deposition. During the synchronous workshop, students are asked to calculate the temperature rises induced by a range of heating patterns, comparing the effects of linear and non-linear heating rates to the final temperature of a surgical target. For their **group activity**, students are challenged to solve a mathematical model that describes the extent of thermal ablation in biological tissue created by High Intensity Focused Ultrasound surgery. Deducing from experimental observation that cell viability has a breaking point at temperatures above 43°C, groups are asked to apply integration techniques to calculate the thermal dose created from the linear heating of a tissue sample and estimate the resulting tissue ablation.

3.4. Learning goals/objectives

The learning goals for MMA1, as articulated in the course outline, are to:

- *recognise how mathematical ideas are embedded in engineering contexts;*
- *represent real-world engineering systems in a mathematical framework;*
- *identify and draw upon a range of mathematical concepts, including Calculus, Linear Algebra, Differential Equations and Statistics to analyse specific problems and identify the appropriate mathematics to realise a solution;*
- *employ appropriate computer modelling techniques to efficiently solve and evaluate the performance of engineering systems;*
- *relate the behaviour of the output of mathematical models to the underlying physical or conceptual models of interest;*
- *carry out engineering problem-solving both collaboratively in a team and independently;*
- *present and interpret mathematical results in effective and appropriate ways to varied audiences, including non-mathematical engineering audiences.*

3.5. Assessment

MMA1 incorporates both formative and summative assessment.

The formative assessment is embedded in the asynchronous materials (via quizzes) and synchronous activities and problems during the synchronous 'live' workshops. In most cases, students are provided with instant feedback on these assessments.

All summative assessment is mandatory and connected to the Core Topics element of the course. For the 2020/21 course, it brought together three elements that spanned the full academic year:

- **individual coursework (40%):** students were asked to complete two items of individual coursework during the 10-week course that assessed their technical skills, creativity and programming skills. Both items were set in the context of the weekly 'scenario', with students asked to develop models to explore the real-world problem. One piece of coursework, for example, looked at the levels of water pollution in a lake ecosystem and asked students to "*derive an expression for the time that the authorities have to act for the clearing of the lake*".
- **24-hour exam (30%):** at the close of the academic year, students took an 'open book' exam designed to assess their mastery of the core mathematical concepts. The exam was designed to be two hours in duration, undertaken online over a 24-hour period.
- **individual project (40%):** following the completion of the course, students were asked to complete a four-week project designed to synthesize their learning and apply this to an in-depth scenario. The project focused on the impact of climate change on the Great Lakes, a chain of freshwater lakes in the US. Students were asked to create a water balance model that could be used to inform government policy for climate change. Although this project was set as an individual piece of work in the 2020/21 course, the intension is for this to become a group project in future academic years.

3.6. The teaching team

The teaching team for MMA1 in 2020/21 consisted of over 60 individuals and comprised:

- the course lead (who: co-led the design and development of the course; and co-led the development and roll-out of training for the teaching team);
- the school's learning technologist (who: co-led the design and development of the course; co-led the development and roll-out of training for the teaching team; led the development of the MMA1 learning management platform). He was supported by two other learning technologists to support the student and staff experience of the online platform;
- five academics from across UCL Engineering (who: co-developed the asynchronous material associated with the mathematical Core Topics and one or more of the weekly 'scenarios'; and led one or more 'live' workshop each week);

- twelve academics from the 8 departments on MMAI (who: led facilitation of the 'live' weekly workshops for students in their department and mark assessments);
- 40 PGTAs (who: facilitate the 'live' weekly workshops, for both the Core Topics and Computational Modelling; co-develop the MATLAB exercises; mark coursework; and post responses to students' questions posted on the online Moodle forum).

All members of the teaching team met online on a weekly basis during the course design and preparation phase (from July to September 2020) and during its synchronous delivery phase (from September to December 2020) where they were able to discuss any particular challenges faced.

The teaching team was offered a two-hour training programme in advance of the course (in addition to the mandatory IEP training for all PGTAs). The MMA1 training, in which most members of the teaching team participated, provided an overview of the priorities for each element of the course and explored key topics in online teaching and learning, such as how to build student engagement online.

3.7. Technology used

The following applications were used in the 2020/21 MMA1 course:

- almost all synchronous and asynchronous learning materials were delivered through the learning management systems Moodle[4];
- the programming language MATLAB[5] was used for computer modelling in conjunction with 'automated' online feedback provided through Grader[2].

Source of evidence

The case study for UCL Engineering (including Part A, this review of MMA1, and Part B, the review of the 'institutional context') drew upon one-to-one interviews with 21 individuals: UCL's Vice Provost for Student Experience; the Director of the UCL Arena Centre for Research-Based Education; the Director of the IEP; the Vice Dean Education of UCL Engineering; the MMA1 course lead; the UCL Engineering learning technologist; nine UCL Engineering academics (including three departmental leads for MMA1 and two Connected Learning Leads); two PGTAs engaged on MMA1; and four UCL Engineering undergraduates (all of whom participated in MMA1 in 2020/21).

Further information about the methodology for development of CEEDA case studies is given at the project website[6].

[4] Moodle: https://moodle.org
[5] MATLAB: https://uk.mathworks.com/products/matlab.html
[6] CEEDA case study structure and approach: https://www.ceeda.org/about#case-studies

Undergraduate engineering student intake (1st year cohort 2020/21):	**≈ 1350**
Number of engineering faculty:	**≈ 300**
Duration of undergraduate engineering degree (to BEng):	**3 years**

UCL, UK

Case Study Part B – Institutional context

1. Defining features of UCL's engineering education

The engineering school at UCL (UCL Engineering) brings together ten departments of engineering, technology and computer science. Historically, almost no connectivity existed between the undergraduate programmes offered by these departments; they operated autonomously, with most following a largely traditional, teacher-centred approach. In 2014, UCL Engineering launched the Integrated Engineering Programme (IEP)[1], a root-and-branch reform to undergraduate education across the school. Three features set apart the IEP's approach. It:

1. **connects students' learning across disciplines:** the IEP established a common school-wide curricular structure, which embeds opportunities for students from across UCL Engineering to come together to engage in shared multidisciplinary learning experiences;
2. **immerses students in authentic problem solving:** the first two years of the IEP curriculum is structured around five-week cycles; the knowledge and skills acquired by students in the first four weeks is applied to a one-week 'scenario' in the final week when students work in groups to tackle a real-life societal challenge;
3. **develops students' professional skills and mindsets:** from the first year of study onwards, emphasis is placed on student self-reflection and the development of professional capabilities such as critical thinking, creativity, decision-making and team work.

The successful delivery of the IEP undoubtedly benefitted from three other innovations that were rolled out at UCL at around the same time. The **first** was the launch of the *Connected Curriculum*[2] in 2014: a UCL-wide initiative designed to connect students' learning with both university research and authentic problems facing the world. The **second** was a radical reform of UCL's academic career pathways in 2017[3], which opened up new career opportunities for faculty on the basis of their contribution to education. The **third** was the establishment of the *Centre for Engineering Education*[4] (CEE) in 2015. Described by one interviewee as "*the external arm of the IEP*", the CEE aims to inform and foster a community of practice in engineering education research and innovation, bringing together instructors and educational experts at an institutional, national and global level.

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

[2] Connected Curriculum: https://www.ucl.ac.uk/teaching-learning/connected-curriculum-framework-research-based-education

[3] UCL Academic Career Framework: https://www.ucl.ac.uk/human-resources/policies/2021/mar/academic-career-framework

[4] UCL Centre for Engineering Education: https://www.ucl.ac.uk/centre-for-engineering-education/

2. UCL's experience of emergency teaching in engineering

2.1. Emergency teaching restrictions

In response to the COVID-19 pandemic, UCL took a 'safety first' approach to its emergency teaching restrictions, characterised by one interviewee as "*a mixture of pragmatism and the extreme end of the spectrum in terms of safety*". UCL is home to a number of prominent global experts in public health and this expertise base undoubtedly guided their approach, making it one of the first UK universities to suspend all in-person teaching (from 13th March 2020) and announce its plans for a fully-online curriculum throughout the 2020/21 academic year. While all curricular teaching and assessments were delivered online during this academic year, some optional 'enrichment' activities were held on campus between September and December 2020. Characterised as being "*educationally valuable, but not part of the core learning*", these 'enrichment' activities included informal talks, tutorials and lab exercises.

In mid-March 2021, UCL announced that the 2021/22 academic year would be delivered in a blended mode, termed "*blended by design*", with in-person sessions focused primarily on practice, practical, interactive and group-focused activity. Where lecture classes are very large and unlikely to enable meaningful interaction, instructors are encouraged to consider online approaches if appropriate.

2.2. Managing the transition to emergency teaching

Interviewees consistently characterised UCL as "*quite a bottom-up 'let all the flowers bloom' type of institution"*, with an open and flat hierarchy. Despite its wide disciplinary base and size – spanning twenty thousand undergraduates – the university has historically taken a highly consultative approach: almost all major institutional changes have been built on community-wide dialogue and consensus. The immediate closure of campus and pivot to online learning in March 2020, however, necessitated a rapid, top-down decision-making process that was described as "*just the opposite of what we do at UCL*". The university established what was termed a "*Gold, Silver, Bronze crisis management structure"* (GSB)[5]: a protocol often adopted during disaster response by UK emergency services that separates strategic, tactical and operational decision-making. Most of the key decisions made through this GSB approach were relayed to the UCL community via virtual town hall meetings: "*if there was an issue that we needed to talk about, we just got all the important people into a virtual room and we had a town hall*". Although in-person town hall meetings have long been a feature of UCL, interviewee feedback suggested that the virtual format, and the importance of the information being relayed, drew much larger and more diverse audiences following the introduction of emergency teaching. With each focused on a different topic of particular interest, such as the first-year experience or the recording of lectures, these virtual town hall meetings were held up to twice a week during the summer of 2020, and allowed major

[5] Gold, Silver, Bronze crisis management structure: https://www.ucl.ac.uk/coronavirus/ucls-planning-and-response/covid-19-crisis-management-structure-ucl

decisions to be conveyed rapidly and clearly. In conjunction with the Unitu[6] 'student voice' platform, virtual town halls were also used as a mechanism to capture community-wide experiences and feedback on these key topics. Indeed, it is interesting to note that, although the GSB command structure was only employed for the first six months of emergency teaching, virtual town hall meetings have continued to be a regular fixture at UCL, with community feedback as a major focus.

The pivot to emergency teaching in March 2020 came two weeks prior to the end of UCL's second term of the academic year; the third and final term is almost exclusively devoted to end-of-year exams for undergraduate programmes. The early focus for managing UCL's online pivot at the undergraduate level was therefore on assessment: how best to deliver the end-of-year exams remotely. In light of the size of UCL's undergraduate population, their geographical spread across time zones, and concerns about the capacity of the university's learning management system, the decision was made that all UCL exams would be online 'open-book' assessments, each undertaken over a staggered 24-hour period. The process of transitioning the exams to the new online format, for many, shone a light on "*the scale of how much assessment we do*" at the undergraduate level, with 1086 items of assessment planned for the end of year exams in UCL Engineering alone. In particular, it was observed that half of all undergraduate exams were taken by first-year students. In response, and as a means of reducing the overall assessment burden and the stress placed on students, UCL replaced all first-year exams with a single integrated assessment. Termed Capstone Assessment, it 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*". Although UCL offered examples of how such a synthesis assessment might be achieved, it was left to each department to design their own approach. Across UCL Engineering, the first-year 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 *Civil, Environmental and Geomatic Engineering* programme. A number of interviewees went on to suggest that assessment had long been an "*Achilles heel*" for UCL Engineering: while the IEP had radically reformed the curriculum, the end-of-year exams were left largely untouched. They went on to note that "*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… A lot was learnt around assessment*".

In parallel with the roll-out of end-of-year exams, preparations began for the 2020/21 academic year. Interviewees noted that the early announcement of UCL's fully-online delivery for the 2020/21 academic year offered clarity to instructors, and ensured that "*time was not wasted*" by preparing for alternative scenarios (such as blended or hybrid teaching) depending on the COVID-19 restrictions in place. Interviewees nevertheless suggested that the summer vacation "*was a mad scramble to prepare for the start of term*". Within UCL Engineering, a major focus for the online pivot was the team-based projects that punctuate the IEP curriculum: in particular, how to design these student-centred and collaborative activities for delivery online. One added burden for the 2020/21 academic year was the

[6] Unitu Student voice platform: https://unitu.co.uk

size of the incoming first-year cohort. 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) due to be held in 2020 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%, from around 900 to 1350. As the school faced its first semester of fully-online teaching, therefore, it also had to support an out-sized incoming student cohort, most of whom were unlikely to meet peers face-to-face throughout the academic year.

Despite the challenges, the online pivot at UCL undoubtedly benefitted from considerable institutional investment in its teaching and learning workforce. Over the preceding decade, the cadre of education-focused faculty that had grown considerably; in addition, a range of new roles were established in response to emergency teaching. These roles included *Student Success Advisors* (to offer mentorship and advice to first-year students), a significant expansion of instructor hours allocated to Post Graduate Teaching Assistants (PGTAs) and (in the case of UCL Engineering) an increase in the number of Learning Technologists allocated to the school from one to four and the appointment of new undergraduate teaching assistants. In addition to this investment in human resources, the transition of UCL's engineering programmes to online delivery was guided by two broad strategies – driven by the university and the school respectively – as outlined below.

The **first strategy** was to establish a clear benchmark for what constitutes minimum acceptable practice for online education at UCL and to offer instructors targeted support for meeting this threshold. In April 2020, UCL launched the *Connected Learning Baseline*[7] which (building upon the university's *Connected Curriculum* approach[2]) provides a checklist of components and features that embody good practice in online teaching and learning. A web of information, resources and support mechanisms were put in place to assist instructors to meet this Baseline when pivoting their courses for online delivery. These included an asynchronous, eight-hour professional development course[8] in online learning (in which half of UCL's 6000 instructors have already participated) and the appointment of *Connected Learning Leads* in each department (to inform and coordinate the development of digital learning resources within that discipline). At the same time, and in response to the online pivot, 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[9], much of the support offered by the LTU focused on helping instructors to meet the Baseline. This included: training programmes in online learning (including a mandatory course for all PGTAs); technical advice (such as how to record videos from home); and pedagogical guidance (such as how to conduct formative assessment online).

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[7] Connected Learning Baseline: https://www.ucl.ac.uk/teaching-learning/publications/2020/may/ucl-connected-learning-baseline

[8] Connected Learning Essentials course: https://www.ucl.ac.uk/teaching-learning/education-planning-2020-21/staff-development-prepare-teaching-and-assessment-2020-21/ucl-connected

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

The **second strategy** to support the online pivot was specific to UCL Engineering and involved seeding exemplars in online education that went beyond the Baseline, to inspire and 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 of the 'shared' IEP courses that bring together students from across 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 (to advance pedagogical development in active online learning); a dedicated LTU consultant (to support course design and planning); and a student assistant (to help develop resources and evaluate teaching materials). A major focus for 'gold' courses was to embed an active and collaborative approach throughout the synchronous and asynchronous activities. It should be noted that one of these 'gold' courses was Mathematical Modelling and Analysis 1 (MMA1), as described in Part A of this case study.

Interview feedback suggested that, in combination, these two strategies have been highly effective in driving the rapid development of a robust set of online engineering courses that, in the words of one university leader, "*put technology and e-learning at the heart of what we were doing*". With multiple opportunities for active learning and collaboration with peers, student participation and engagement in the UCL Engineering Virtual Learning Environment (VLE) appear to have been high.

2.3. Addressing the challenges of emergency teaching

Interviewees pointed to a range of challenges faced by UCL Engineering during the period of emergency teaching. Three challenges were identified repeatedly, as described below.

The **first challenge** was sequencing and managing students' workload. Many interviewees noted the extent to which the online pivot had affected students' ability to plan, prioritise and manage their learning which, in the words of one, often left them feeling "*overwhelmed and overworked*" at a time of physical isolation from peers and instructors. In particular, they 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 how their courses are structured 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 went on to note that the online pivot stripped many of these informal interactions from the students' learning experience. This was understood to have left many students unable to conceptualise the structure and expectations of their courses, as well as gauge the relative priority of different course elements and topics: "*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*". Interviewee feedback suggested that these experiences had led to both high attainment and high levels of stress amongst students. Many went on to note that one of the key 'lessons learnt' from the experience of emergency online teaching at UCL Engineering was the importance of clearly articulating the structure, deliverables and key learning goals of each course and "*walking students through the semester, step-by-step*". Particular attention was also paid to establishing regular 'office hours' sessions to provide informal help and support to both individual students and projects teams. Another strategy that proved successful in fostering peer support and addressing students' specific concerns was the widespread use of asynchronous online forums, which were established across UCL Engineering both at a course level and programme level.

The **second challenge** repeatedly identified was establishing a suitable online environment for effective team-working. Interviewee feedback pointed to a number of practical barriers that worked against open and productive group collaboration in an online environment. One was simply the fact that, as emergency teaching progressed, the proportion of students that switched their web-cams on for group working sessions progressively decreased: "*sometimes there is just a blinding silence in the breakout room and all of the cameras are off*". Another was the home environment in which many students were working, as noted by one UCL Engineering leader:

> *"one of the things that has come out most strongly in all of this is just the different resources that different students have, whether it's stable wi-fi, somewhere to work, home life, other responsibilities, all the sorts of things that you didn't know when they were in-person… 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".*

UCL Engineering's team projects also faced the challenge of cross-time zone working. The school's undergraduate population is a very international group. Less than a third (31%) of the first-year cohort that joined the school in 2020/21 were from the UK. In some departments, the proportion of non-UK students is higher still: in *Electronic and Electrical Engineering*, 85% are drawn from outside the UK. With most based in their home countries during the 2020/21 academic year, students were engaging with the online UCL curriculum from a wide range of time-zones. This time-zone diversity presented a particular challenge for synchronous participation in the intensive, full-time, team-based projects that punctuate the IEP, such as the week-long 'scenarios'. One consequence, for example, was that some teams, in the words of one interviewee, "*broke the project down, split up the tasks and worked alone, without really collaborating*". These challenges appeared to be exacerbated for students whose competence in the English "*language is not at a level where they are confident to be able to engage with their teammates online*". UCL Engineering adopted a number of strategies to overcome these challenges. One was to preserve the middle hours of the day in the UK – a time-window most likely to be convenient for students accessing their education from abroad – for team mentorship and guidance. Another was to extend the interdisciplinary project taken by all first year undergraduates from five weeks to eight weeks, to allow more time to build connectivity and trust within each team.

The **third challenge** consistently raised was that of fostering community and connectivity across the engineering student population. While the IEP's online pivot offered a range of mechanisms for collaborative learning through team projects, what was missing were opportunities for students to connect informally outside of the formal curriculum, such as "*after a lecture or in the lift lobbies*". The absence of these interactions was felt most acutely by the cohort of first-year students, most of whom had yet to meet peer students face-to-face. While UCL's student clubs and organisations appeared to have some success in providing online opportunities for students to build social networks, what proved more difficult to re-create online were the "*intellectual interactions rather than the social interactions*": the friendships and communities of support rooted in the shared experience of their engineering programme that help students to connect ideas, extend their thinking and spark new interests. Attempts were made by UCL to bridge this gap, such as through the establishment of *Virtual Common Rooms*[10]: online spaces where students from the same department or course were able to connect together. However, without a clear driver or objective for joining these common room sessions, student participation to date has typically been low. One department that has had more success in engaging students in activities that blend the social and the academic has been Computer Science. During the 2020/21 academic year, a number of Computer Science courses have been delivered via the web conferencing software *Gather.Town*[11], and students have been encouraged to remain in this virtual space between classes to "*walk around, meet each other and play [online] games*". Following the success of a (purely social and optional) all-day online *MegaGame*[12] held in early 2021, UCL Computer Science are also planning a virtual competition for the start of the 2021/22 academic year. Designed to "*build both fun and engagement*", students will be asked to develop and incrementally improve their own algorithms to play an online card game, where success and gameplay will be followed in real time and charted in an anonymised league table.

3. Impact of emergency teaching on future educational approach

Interviewees repeatedly noted that the experience of emergency teaching had called many in the global higher education community to "*ask big questions like 'what is a university for?' and 'what is the value [that] going to university adds?'*" and the UCL community had been no exception. Interviewees, however, went on to suggest that it was still "*too early to make a call*" on how the UCL Engineering education will be impacted in the longer term. For example, it was suggested that the true scale and nature of the effect of the pandemic and emergency teaching upon student mental health was unlikely to be fully understood for months or even years to come. In addition, while the importance of student competencies such as digital literacy, time management and resilience have come to the fore during emergency teaching, no decisions have yet been reached on whether or how they might be accommodated in revisions to the UCL Engineering graduate attributes in the future. Indeed, interviewee feedback made clear that school leaders and instructors were still primarily focused on the immediate challenges of emergency teaching: "*everyone's sort of looking day-to-day at the moment... there is an element of 'we've come out of something that feels like a war zone' and everyone is just still exhausted*".

[10] UCL Virtual Common Rooms: https://www.ucl.ac.uk/students/academic-support/ucl-virtual-common-rooms

[11] Gather.Town: https://gather.town

[12] Stone Paper Scissors games: https://www.stonepaperscissors.co.uk

Nonetheless, while no clear consensus emerged about the long-term impact of COVID-19 on the UCL Engineering education, interviewees consistently anticipated that the consequences of the pandemic would "*quicken the pace*" of a number of major educational changes already underway in the school. This acceleration was understood to be the product of two disruptive factors: the experience of emergency teaching (as a result of which, online delivery was likely be one of the significant teaching modes at UCL for at least two-and-a-half years overall) and the single outsized cohort of students that joined UCL Engineering for the 2020/21 academic year (who will be moving through the engineering undergraduate programmes until 2024). Interviewees spoke, in particular, about how these factors combined would lead to an acceleration of existing changes in three areas, as described below.

The **first area** of accelerated change was expected to be in the embracing of blended learning. The educational model to be adopted by UCL for the 2021/22 academic year is described as "*blended by design*": a blended-learning approach that combines, in the words of one interviewee, "*asynchronous content delivery with meaningful face-to-face activities, like tutorials or projects*". Interviewee feedback pointed to a widespread expectation that this approach would continue beyond the period of emergency teaching to become part of standard practice at the university. Interviewees noted that "*we have come a long way since COVID hit*" in designing and curating online materials that both engage students and support deep learning. In addition, and continuing on the pathway established by the IEP, interviewees suggested that it would soon become the norm that all face-to-face learning in the school would be dedicated primarily to active and experiential learning. Indeed, one university leader predicted that "*we will not be bringing big groups of students on to campus anymore unless it's for meaningful interaction, person-to-person individual peer-to-peer and student-to-teacher interaction. It won't be to sit in some lecture theatre*".

The **second area** forecasted for accelerated change was in the creation of new flexible learning spaces that facilitate informal collaborative learning. Interviewees anticipated that, hand-in-hand with the widespread adoption of blended learning, there would be an acceleration to the reform of UCL's physical estate: "*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*." These informal, flexible learning spaces will not only be utilised for curricular experiences designed for face-to-face delivery, such as team projects and tutorials. In addition, interviewees anticipated that many students would choose to undertake asynchronous online learning activities within such on-campus spaces, often working collaboratively with peers. While open and flexible learning spaces are integral to the design of the UCL Engineering buildings in the university's UCL East[13] development, due to open in 2022, some interviewees suggested that "*UCL will need to think carefully about what spaces we need on our [main] campus and how to use timetabling to make sure that students are able to find the best places to work at a given time*".

[13] UCL East: https://www.ucl.ac.uk/ucl-east/

The **third area** where interviewees anticipated fast-tracked change was to the educational culture. Over the past five years, with the introduction of new student-centred educational models (such as the IEP and the *Connected Curriculum*[2]) and a new academic career framework[3], interviewee feedback pointed to a progressive improvement to the status and recognition of teaching and learning at UCL. The effect of this can be seen most clearly in the number of education-focused faculty that have been promoted to senior academic roles in recent years. Some interviewees went on to suggest that the experience of emergency teaching had helped to reinforce and accelerate this ongoing cultural shift at the university. They described, in particular, how a cohort of education-focused academics had "*stepped up to the plate*" during emergency teaching to take on new leadership positions, such as the Connected Learning Leads, that established many as mentors and "*focal points for development and support of their research-oriented colleagues*". Some cautioned, however, that "*it is not a given that this will equate to a long-term elevation in status*" of education-focused academics at the university. They noted that this group "*have taken a disproportionate amount of the burden [of emergency teaching]"* and risked replacing educational leadership and innovation with "*ever increasing teaching loads as researchers became frustrated [with emergency teaching] and want to get back to their research*". Nonetheless, interviewee feedback suggested that the experience of emergency teaching 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 this cohort of education-focused faculty has made.

Indeed, the ways in which UCL has navigated and weathered the online pivot was understood to have "*endorsed a lot of the decisions the university has made*" in recent years to build capacity in and support for teaching and learning. Many also went on to compare UCL's response to emergency teaching to UK peer universities, commending the support UCL has given to students and staff (regardless of their role or position) and the rapid, clear, and evidence-based approach taken to decision-making. In the words of one faculty member: "*UCL has got a lot of things right... when the big edicts came, they were very clear, they were early, and they were right on point*".

Source of evidence

The case study for UCL Engineering (including Part A, the review of the Mathematics Modelling and Analysis I (MMA1) course, and Part B, this review of the 'institutional context') drew upon one-to-one interviews with 21 individuals: UCL's Vice Provost for Student Experience; the Director of the UCL Arena Centre for Research-Based Education; the Director of the IEP; the Vice Dean Education of UCL Engineering; the MMA1 course lead; the UCL Engineering learning technologist; nine UCL Engineering academics (including three departmental leads for MMA1 and two Connected Learning Leads); two PGTAs engaged on MMA1; and four UCL Engineering undergraduates.

Further information about the methodology for development of CEEDA case studies is given at the project website[14].

[14] CEEDA case study structure and approach: https://www.ceeda.org/about#case-studies

MIT, US

Case Study Part A – Best Practice Activity

Design Challenge One

Distinctive feature of case study

Facilitating collaboration, peer-support and network-building across the student cohort

Student cohort:	**95**
Location:	**100% online**
Duration:	**5 days, full-time**
Date delivered:	**August 2020**
Activity type:	**Master's orientation**
New/existing:	**Reformed course**
Hands-on element:	**Optional**
Cross time-zones:	**Yes**

Abstract

Activity overview

Design Challenge One (DC1) is a five-day activity designed to immerse students in authentic, complex challenges that call upon technical, societal and organisational skills for their solution. As a result of the global pandemic, DC1 in 2020 was pivoted from a face-to-face format to an entirely online delivery; the challenges were framed around the United Nations Sustainable Development Goals. Using an approach inspired by crowdfunding platforms, teams and other stakeholders were each allocated a virtual currency which they were invited to spend through 'backing' other teams in exchange for help and advice. This 'backer' system provided a gateway for students to seek and provide peer support, helping them to build networks and communities despite collaborating remotely.

Independent review

The 2020 DC1 embedded a novel online 'backer' system that explicitly encouraged and rewarded inter-team collaboration. Interviewee feedback pointed to the success of this approach in fostering collegiality, networking and peer-learning across a cohort of students that had never met face-to-face. It is also a model that holds considerable potential to be scaled-up to larger cohort sizes.

Activity details

DC1 is embedded in the one-week orientation Bootcamp for incoming Master's students to the System Design & Management (SDM) programme that is run jointly by MIT's School of Engineering and Sloan Management School. DC1 2020 was delivered across multiple time-zones to participants located in six continents.

1. Activity overview

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. It forms the major component of the one-week orientation Bootcamp designed to introduce incoming students both to system-thinking methods and to the values of SDM and Massachusetts Institute of Technology (MIT). These values include building trust, peer-support and collaboration across the student cohort; harnessing students' capacity to build, connect with and draw upon the MIT community network; and combatting 'imposter syndrome' and the low confidence levels often evident in the incoming student population. The need to embed these collaborative learning goals was further highlighted by the shift to 'emergency teaching' where the 2020 incoming cohort would be participating in DC1 remotely, from a range of time zones worldwide and without face-to-face contact.

A new cohort of second-year SDM students are engaged as Teaching Assistants (TAs) each year. Reflecting SDM's culture of ongoing pedagogical innovation and experimentation, these TAs are encouraged to take a lead in evolving the DC1 experience. This has led to many different variants of DC1 over the years; what has been retained throughout, however, has been the hands-on, face-to-face nature of the activity. The group of TAs engaged in 2020 took the pivot to emergency teaching 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, with each challenge linked to one of the United Nations Sustainable Development Goals (SDGs). For example, one challenge, framed around SGD 1 (No Poverty), asked students to develop a sustainable housing solution for the city's homeless population. 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 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 '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; and 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.

2. Independent review

2.1. Distinctive features

The feature that sets the 2020 DC1 apart from peer experiences worldwide is its approach to fostering a culture of collaboration, peer-learning and network-building across the newly-enrolled student cohort. In particular, members of the teaching team noted that – unlike many ice-breaker activities delivered to incoming students, where the form and focus for collaboration is pre-determined – the 'backer' approach allowed the collaborative element to be voluntary and student-led. As the lead TA noted, each element of the DC1 was designed such that "*teams needed to collaborate to be successful*".

The DC1 teaching team established two mechanisms to advance collaboration and network-building:

- a **dedicated web platform** that showcased each team's progress and allowed peer teams, MIT faculty, SDM alumni and 'guests' from the regional community to award 'coins' to individual teams. The number of coins earned was at the discretion of the backer and could be awarded for a variety of reasons: approval of the team's ideas/approach, recognition of the constructive responses given by the team to external feedback, or gratitude for the help offered by other teams. Coins allocated to backers were released progressively over the five-day activity, to encourage collaboration throughout the week. Teams were asked to provide written feedback to any comments made by current or prospective backers.
- a project **scoring system** that explicitly rewarded inter-team collaboration, and which set the cumulative total points received across all teams as the primary metric of success. In particular, the components of the assessment rubric that were uncapped (i.e. that did not have an upper limit) all related to inter-team collaboration, meaning that teams striving to maximise their scores were further motivated to collaborate. Further information on the assessment rubric is given in Section 3.4.

Students enrolled on the SDM programme were drawn from a range of time zones, cultures and disciplinary backgrounds, and the DC1 'backer' and scoring system offered them a variety of different modes to initiate and advance cross-team collaboration. For example, a student may choose to engage asynchronously, by leaving a comment, asking for help or allocating coins to another team via the web platform; they might also choose to engage synchronously via a Zoom conversation with another team to explore possible areas for assistance. Participants used platforms such as Slack or WhatsApp to reach out to peer teams to identify skills/resources from which they might benefit as well as to ask for help.

Interviewee feedback pointed to the success of this approach in fostering collegiality, networking and peer-learning across a cohort of students that never met face-to-face. It is also a model that offers potential for scaling-up, for example to larger cohort sizes and longer course units. In particular, the coin-based online backer approach could be used as a mechanism to track individual student engagement and flag up individuals who do not appear to be collaborating or interacting through any of the available modes.

2.2. Success factors

The success of the 2020 DC1 was undoubtedly advanced by SDM's long-standing expertise and experience of delivering hybrid learning, with around 40% of SDM students accessing courses online prior to the introduction of emergency teaching. As such, the teaching team and programme staff were already well-placed to deliver distance learning to students across multiple time zones – with effective online tools and support systems already in place – and participants already expected this delivery mode to play a prominent role in their learning across the two-year Master's programme.

In addition to this existing expertise base, interviewee feedback pointed to two inter-related factors that were crucial to the success of the DC1, which are outlined in turn below.

The first success factor was the clarity of vision for the 2020 DC1. Its design and delivery was led by TAs who were predominantly second-year students on the SDM Master's course and had therefore participated in the Bootcamp the previous year. The group was therefore uniquely placed to appreciate both the value of the face-to-face DC1 model and the capacity of the student cohort to adapt to a different approach. This group of TAs brought a clear and coherent vision to the activity, which was underpinned by two priorities: to foster an inclusive culture of collaboration and network-building throughout the cohort; and to advance the MIT philosophy of harnessing innovation and technology for the benefit of society. In redesigning DC1 from a blank slate, the TA team was able to embed these two priorities into every aspect of its design as well as shape its approach around the opportunities offered by the online format, such as through the web platform. As such, they were not simply transferring an existing activity into the online space, but rather exploiting the online environment to create a pedagogical approach that may never have been possible face-to-face.

Secondly, the 2020 DC1 built upon SDM's culture of educational experimentation. This ongoing pedagogical innovation works in synergy with SDM's inclusive and egalitarian approach characterised by one interviewee as "*learning from your peers and the community*". It is in this context that SDM empowers selected members of its second-year student cohort to take a lead in the design and delivery of DC1. The autonomy afforded to the TAs not only allowed them to follow a clear and coherent vision for DC1 (as outlined above), it also exposes the incoming cohort to, in the words of one interviewee, "*the sheer enthusiasm, curiosity and positive tone of the second year students*". In other words, DC1 is used as a mechanism to pass on and foster the distinctive SDM culture of collegiality and common purpose amongst the next generation of students. Interview feedback suggested that this culture was shared by the DC1 participants, teaching team, SDM department, external collaborators and the wider MIT faculty community engaged with the project. Many also noted an "*entrepreneurial team spirit*" amongst the teaching team and a willingness to take on whatever tasks were required to deliver the 2020 DC1; the web platform, for example, was developed by a TA with no professional experience in coding or web design. The focus on tackling authentic sociotechnical challenges facing the region was also understood to bring together the MIT and city community, and foster new ideas and connections which extended beyond the student cohort.

2.3. Challenges faced

DC1 was developed under tight time constraints during the eight weeks prior to the Bootcamp's launch, in a context of some uncertainty about the institutional approach to emergency teaching. MIT had asked the instructors to prepare for three possible emergency teaching scenarios for the fall 2020 semester – fully online, fully on-campus and a hybrid approach – and the decision to shift to fully online teaching was only made a few weeks prior to the start of DC1. The teaching team was therefore required to maintain three different DC1 models in parallel throughout its development process, and only confirm the online model at a relatively late stage. Within this context, interview feedback pointed to three additional challenges facing the development and delivery of the 2020 DC1, as outlined below.

The **first challenge** concerned the perceived risks of moving away from a tried-and-tested DC1 approach. Looking across programmes worldwide, the online pivot for similar hands-on collaborative experiences typically involved the replication of individual components of the activity in the online domain, with the hands-on element often delivered through Arduino/Lego kits shipped out to participants or through asking students to create 3D digital models of the solutions. The proposed model for the 2020 DC1, in which the activity was designed from a blank sheet with no hands-on component, was undoubtedly higher risk. Interviewee feedback suggested that concerns were raised by teaching team members and the SDM faculty in the early weeks of the 2020 DC1 development about the potential risks of root-and-branch reform to the structure and focus of the DC1 project, particularly during a period of uncertainty and emergency teaching. It was also noted, however, that, once consensus was reached to move forward with the new approach, the teaching team was provided with unwavering support from the SDM department and MIT.

The **second challenge** was to balance the drive to build student engagement against the risks of overloading participants with multiple activities and deliverables. The teaching team clearly invested considerable time in the design of each element of DC1 to maximise student motivation and immersion in the MIT culture, regardless of students' background and expertise. As with many of the activities highlighted through the CEEDA project, however, interviewee feedback suggested that student exhaustion and screen fatigue was a prominent issue by the close of DC1.

The **third challenge** was the limitations of the online delivery. While the SDM programme has long been delivered in a hybrid format, DC1 has been one of the few components that, historically, all students have been required to attend in person. The key drivers for this are twofold: it allows students to apply and explore the physical application of their ideas through hands-on building; and it offers an intensity of experience that facilitates rapid team-bonding and multiple opportunities for informal interaction and connectivity. While interviewee feedback suggested that important aspects of the 2020 DC1 approach with respect to community and cooperation were likely to be retained in future years, the activity would almost certainly revert to a face-to-face delivery as soon as COVID-19 restrictions allowed in order to preserve the hands-on learning and intensity of cohort boding.

3. Activity details

SDM is delivered jointly by two of MIT's schools: the School of Engineering and the Sloan School of Management. The overall goal of the SDM programme is "*to educate mid-career professionals to think effectively and creatively by using systems thinking to solve largescale, complex challenges in product design, development and innovation*".

DC1 is embedded into the orientation Bootcamp for the SDM Master's and is the first of eight team-based projects that build progressively in complexity throughout the two-year programme. DC1 is designed to allow students, in the words of one interviewee, "*to apply systems thinking and methods to a local problem*". In previous years, the challenges have included MIT themed robotic contests, novel uses of drones, and the construction of Rube Goldberg machines.

3.1. Structure of the activity

Integrated into the Bootcamp, the 2020 DC1 was a fully online activity, delivered over a five-day period in late August 2020. Most elements of the 2020 DC1 were delivered synchronously, although some material was delivered in duplicate for students across different time zones (see Section 3.4). Synchronous sessions were held in the mornings of the first and final day of the Bootcamp (8am until midday ET).

The four-hour session in the **first morning** of DC1 was devoted to introducing the cohort to the project and assigning the challenges. This included:

- a 'kick-off' session, led by the Mayor of the City of Cambridge, where each of the 17 SDG-linked challenges were randomly assigned to one of the cohort's 17 teams;
- an introduction to the goals and structure of the DC1 project;
- a Q&A session with stakeholders from the City of Cambridge, where students were able to explore the challenges in the Cambridge context and identify potential sources of further information and support;
- skill development sessions, in topics such as team working across cultures, distributed leadership and oral presentations.

The four-hour session in the **final morning** (on day five) of DC1 was devoted to team presentations and wrap-up of the project. This included:

- a three-hour session for all teams to deliver their final 10-minute presentation to the full cohort and the judging panel, followed by a closing ceremony;
- structured sessions for self- and group-reflection on what had been learnt during the week.

During the remaining three mornings, the 'core' four-hour sessions were devoted to non-DC1 activities, introducing students to the SDM programme and the key elements of the core curriculum. Outside of these synchronous morning sessions, teams were expected to work independently on their DC1 projects, with team deliverables scheduled throughout the week (see Section 3.2). Teams were asked to check-in with their assigned TA each day for 15 minutes to outline progress.

Please note: a suite of activities not connected to DC1 were also delivered prior to the Bootcamp to orient students and provide an introduction to both SDM and MIT.

3.2. The challenges and deliverables

Each of the 17 teams participating in the 2020 DC1 project were randomly assigned to a different sociotechnical challenge facing the City of Cambridge. Each challenge was framed around one of the 17 Sustainable Development Goals (SDGs). Teams were asked to develop a "*tangible solution*" to their assigned challenge, which could include (but were not limited to) a website or an app.

One sample challenge brief is given below, which relates to SDG 16 on *Peace, Justice and Strong Institutions*:

> ***Restructuring Police Entity:*** *The City of Cambridge is determined to ensure fairness among its residents. In recent months, the unfortunate death of George Floyd has reignited many constructive conversations on the city's police force. Rather than focusing only on the fairness conversation, the city could also explore ways to improve and modernise current policing practices. Hence, the city is looking for a solution on how to automate routine traffic enforcement to eliminate many nonessential encounters between the police and the civilians.*

These challenge briefs were developed by the DC1 TAs in collaboration with a councillor from the Cambridge City Council.

The key deliverables for the five-day activity are summarised below:

- **by the beginning of day 2**: teams were asked to produce a draft project webpage providing an introduction to the team's challenge and emerging ideas;
- **by the beginning of day 3**: teams were asked to upload a one-minute video to their project webpage to outline their challenge and solution, to be used as a means to collect feedback and foster inter-team collaboration;
- **by the end of day 4**: teams were asked to have both benefitted from and provided significant support and feedback to peer teams, as documented on the web platform;
- **by the beginning of day 5**: teams were asked to deliver an eight-minute presentation to a panel of judges comprising SDM faculty, TAs and stakeholders from the City of Cambridge. These presentations incorporated two core components: (i) an explanation of the problem from a sociotechnical perspective; and (ii) a solution in the form of a tangible demo, which could include an app or website.

3.3. Learning goals/objectives

Designed as an 'onboarding' activity to the SDM programme, DC1 is designed "*to support students in developing the skills, knowledge, attitudes and connections to be successful in MIT*". In particular, the three core goals for both the Bootcamp and DC1 are:

1. **Cohort bonding:** fostering a collegial and collaborative culture amongst the incoming student cohort. Prior to 2020, students had been required to attend the Bootcamp in person; establishing such a community bond was understood to be a priority in a programme in which many students would engage via a blend of face-to-face and remote learning.
2. **Orientation:** introducing students to SDM and providing tools to navigate MIT. This included introductory workshops to key SDM themes (typically delivered during synchronous sessions during the five days) and practical information on MIT, such as the academic integrity rules or registration information (much of which was provided via information packs in advance).
3. **Reintroduction to university life:** support and information on re-adjustment to university life after a number of years working in professional careers, following completion of their undergraduate degree. Particular focus was given to addressing personal concerns (such as 'imposter syndrome' of being accepted into an institution such as MIT) and practical issues (such as securing local childcare) that incoming SDM Master's students might have.

3.4. Cross time-zone working

The 95 students participating in the 2020 DC1 were based across six continents and were therefore accessing the remote activity from a wide range of time zones. The DC1 teaching team accommodated this time zone diversity in a number of ways. They first identified a 'core' four-hour time-window that would be most convenient for the largest proportion of students. This core window (from 8:00am to midday Eastern Time) was reserved for synchronous activities in which all students were required to participate. These activities included the introduction to DC1 on the first morning of the Bootcamp and the DC1 team presentations on the final morning; sessions in the intervening mornings were devoted to non-DC1 activities, such as introductory classes for SDM and MIT orientations. All of these activities were recorded and made available for students to view within a few hours of their delivery. Any Bootcamp activities scheduled outside this four-hour core window were offered in duplicate, across different time zones. So, for example, speakers were asked to deliver each talk in two different times of the day, and recordings of 'live' sessions were played back at alternative times with a TA and/or faculty member on hand to provide feedback and answer questions.

In addition, membership of the DC1 teams was determined by the time zones in which they would be working, while still maintaining cultural and geographical diversity amongst teams. Prior to their participation in DC1, students were asked to identify the most convenient time windows for them to engage in group projects. Feedback from participants suggested that the majority of team-work was conducted synchronously and as a group.

3.5. Team and cohort assessment

Team assessment: the assessment protocol for each team in the 2020 DC1 is given in the table below. Points were awarded across three main components:

1. systemic goal achievement: elements related to systems thinking and the quality of the team's solution;
2. -ilities: performance attributes of the team's solution beyond the system's core function, such as reliability, adaptability, scalability, etc. (terms that typically end in "ility");
3. collaboration: the extent to which each team member contributed to their project, and the extent to which each team collaborated across the cohort.

The three elements where team scores were uncapped, without an upper limit – shown in 1d, 2b and 3c in the table below – were all linked to inter-team communication and collaboration. In the case of 3b, the 'level' of contribution made by other teams (small, medium of large) was determined by the team receiving help and subsequently checked by one of the TAs.

1. Systemic goal achievement	
1a. How well were the problem and the stakeholders defined in the final deliverable?	10 points
1b. How well does the final concept demo work across a variety of use cases?	25 points
1c. Does the proposed concept address one of the UN sustainable goals in Cambridge?	25 points
1d. BONUS – extra points for each additional UN sustainable development goal addressed in Cambridge	5 points each
2. -ilities	
2a. How technically complex is the proposed concept with respect to user input (e.g. how many sources of data is the concept linked to)?	15 points
2b. How multidisciplinary is the proposed concept (e.g. how many engineering disciplines does is draw upon)?	1 point per discipline
2c. How generalisable is the proposed concept beyond the City of Cambridge?	10 points
3. Collaboration	
3a. How involved was each team member in the ideation and development of their team's proposed concept (captured using the TEAMMATES online peer evaluation software[1])?	30 points
3b. Level of external support for the project on the website, based on the website's crowdfunding interface	10 points
3c. Help received by other teams for contributing to their deliverable	+1 point (small) +6 points (medium) +9 points (large)

[1] TEAMMATES: https://teammatesv4.appspot.com/web/front/home

Cohort-wide assessment: for the success of the activity as a whole, a threshold score of 1443 cumulative points had to be achieved across all teams. This threshold score was determined by the teaching team as constituting 10% above the average score that each team would be expected to achieve. The 2020 DC1 cohort surpassed the goal, and students were able to support a local charity.

3.6. The teaching team

The full 2020 Bootcamp teaching team included a large number of SDM faculty, teachers and TAs who contributed to the orientation and introductory material delivered to the new starting cohort. The teaching team engaged in the design and delivery of the DC1 project is listed below:

- lead TA, who led the design and delivery of DC1, and coordinated with other members of the teaching team;
- eight additional TAs, some of whom led critical aspects of the activity design, such as the development of the web platform or the assessment rubrik. Almost double the number of TAs were engaged for the 2020 DC1 than had been involved in previous years;
- two SDM Programme Directors, who provided advice, support and mentorship for the development and delivery of DC1;
- four MIT faculty members who delivered four one-hour sessions to support the 'technical' aspect of the challenges (in system thinking, system architecture, system engineering, and project management) and a number of MIT faculty members and external guest lecturers to deliver sessions to support the 'social' aspect of the challenges (including effective cross-cultural teamwork, ethical standards and diversity);
- one councillor from the City of Cambridge who co-developed the 17 challenges, based around authentic issues facing the city;
- 17 regional contact points. Each team was given contact details for one or more individuals, typically from outside MIT, who would be well placed to offer advice or contextual information about the application of their challenge within the City of Cambridge. Teams were encouraged to reach out to these individuals, and use these connections to further build their networks.

3.7. Participants

95 students participated in the 2020 DC1: the full incoming cohort to the SDM programme. Students were early- or mid-career professionals, typically having 8–10 years of professional experience, with around 80% from an engineering background. In 2020, students were drawn from 23 countries and six continents. In a typical year, around one-third of SDM students engage with the programme remotely, although all are required to attend in person for three group projects during the first year of study (including the DC1) and for one semester during their second year.

The DC1 teams were pre-assigned. Membership of each team was determined in advance by the teaching team to ensure an even distribution of skills, experience and time-zone compatibility.

3.8. Technology used

The following applications and technologies were used in the delivery of the 2020 DC1:

- a new web platform was developed in-house by the TAs to house each team's project web page and operate the 'backer' coin system;
- dedicated Slack and WhatsApp channels were established to connect the full cohort, in which students could ask for and offer assistance to other teams;
- a Kahoot[2] game was created for the cohort to connect and learn more about one another;
- the TEAMMATES[1] online peer evaluation software was used to gather feedback on the relative contribution of each team member;
- Canvas[3] was used to provide materials to students, including video recordings of sessions;
- although teams were free to develop any form of 'tangible demo' for their final solution, they were introduced to App Inventor[4] as a low-barrier-to-entry app development environment.

Source of evidence

The case study for MIT (including Part A, this review of the DC1, and Part B, the review of the 'institutional context') drew upon one-to-one interviews with 22 individuals: the Associate Dean of Engineering; the university Vice Chancellor; the Dean for Digital Learning; the Director of the Teaching + Learning Lab; the Executive Director of NEET; the NEET curriculum designer; two faculty members (and instructors from 2.007); the Executive Director of the SDM programme; the Academic Director of the SDM programme; three Teaching Assistants from SDM; three SDM students; five engineering undergraduates and one Councillor from the City of Cambridge.

Further information about the methodology for development of CEEDA case studies is given at the project website[5].

[2] Kahoot: https://kahoot.com

[3] Canvas: https://www.instructure.com

[4] App inventor: https://appinventor.mit.edu

[5] CEEDA case study structure and approach: https://www.ceeda.org/about#case-studies

MIT, US

Case Study Part B – Institutional context

Undergraduate engineering student year group (2nd year cohort 2020/21):	**≈ 850**
Number of engineering faculty:	**≈ 400**
Duration of undergraduate engineering degree (to BSc):	**4 years**

1. Defining features of MIT's engineering education

A striking feature of the Massachusetts Institute of Technology (MIT) undergraduate curriculum is the disciplinary breadth to which students are exposed. Regardless of their major, all MIT students are required to study what are termed *General Institute Requirements* (GIRs) which comprise around half of the undergraduate curriculum (17 of the 35 subjects). While some GIRs focus on foundational sciences (such as Biology and Mathematics), a significant proportion are devoted to the liberal arts, including four courses in Communications and eight courses in Humanities, Arts and Social Science.

Arguably, the defining feature of MIT's engineering education, however, is encapsulated in its motto "*Mens et Manus*" – mind and hand. It is a model that, in the words of one interviewee, "*blends the practitioner and the theoretician*" with an apprenticeship-style approach to experiential and 'hands-on' learning. This experiential approach can be seen most clearly beyond the core engineering curriculum: in MIT's elective courses, co-curricular activities and suite of maker-spaces across campus[1]. For example, over 90% of MIT's undergraduate engineers participate in the *Undergraduate Research Opportunities Program* (UROP)[2], where they engage in research projects in collaboration with MIT faculty, typically as a co-curricular experience. Supported by a broad infrastructure of resources, training programmes and opportunities, many co-curricular activities also blend experiential learning with entrepreneurship and innovation. One example is the *Sandbox Innovation Fund Program*[3].

The past five years has marked a new chapter in the university's blending of 'mind and hand' through the establishment of NEET[4] (*New Engineering Education Transformation*). This programme brings together MIT's emphasis on experiential learning with a project-based, multidisciplinary approach designed to better prepare students to tackle the major challenges facing society. Since its launch in 2017, NEET has grown to represent the fourth largest undergraduate programme at MIT. NEET students follow one of five interdisciplinary 'threads' in areas such as *Autonomous Machines* and *Digital Cities* that are drawn from courses in different engineering departments and connected by hands-on, authentic projects. Building students' skills and mindsets is a major focus of NEET, with its design guided by what are termed 'NEET Ways of Thinking': 12 capabilities that include 'creative thinking' and 'analytical thinking'.

[1] MIT Makersystem, Project Manus: https://project-manus.mit.edu/mit-makersystem

[2] Undergraduate Research Opportunities Program (UROP): https://urop.mit.edu

[3] MIT Sandbox Innovation Fund: https://sandbox.mit.edu

[4] NEET (New Engineering Education Transformation): https://neet.mit.edu

2. MIT's experience of emergency teaching in engineering

2.1. Emergency teaching restrictions

On 16th March 2020, the MIT President announced the closure of the university campus, with spring classes to resume fully online from 30th March. Soon after the semester relaunch, MIT established a suite of resources[5] to support university operations during the period of COVID-19 restrictions. This included the development of an app – the *Covid Pass*[6] – to manage campus access, testing, contact tracing and vaccinations of MIT staff and students in collaboration with the campus medical centre.

Throughout the 2020/21 academic year, the majority of MIT classes were delivered online, under an institutional approach characterised as "*anything that can be remote, will be remote*". However, from September 2020, seniors (final year students) were given dispensation to return to campus to participate in specific hands-on or lab-based courses that could not be delivered remotely. From February 2020, all students were invited back to campus to work remotely from dorm rooms and to engage in specific hands-on or lab-based courses face-to-face.

2.2. Managing the transition to emergency teaching

As in many universities across the world, the online pivot at MIT was rapid: instructors had two weeks to prepare for a fully online educational delivery. To support this transition, the university communicated two clear messages to its faculty.

The **first** was to recalibrate what could be achieved in 'emergency teaching' conditions, particularly in the early weeks of the online pivot. In the words of one university leader, "*two thirds of the content, two thirds of the quality is enough*". Instructors were encouraged to focus on the core objectives and content of their courses and the emphasis on 'high stakes' assessments, such as mid-term tests, was significantly reduced: "*you don't want a winner takes all environment when you're living in a pandemic*". For the remainder of that semester, MIT moved to a 'pass/no record' grading system for all undergraduates (such that students either passed the class or receive no record of having taken it).

The **second** message for instructors was, in the words of one university leader, "*to make a plan, decide how you are going to teach [remotely] and then come ask us for help and support*". In line with the deeply embedded MIT culture of faculty autonomy, the onus was first placed on instructors to revise the design and focus of their courses for online delivery. The university then facilitated delivery of these plans by establishing an infrastructure of support and resources, many of which were in place prior to semester relaunch on 30th March 2020. For example, a number of MIT's functions – including the *Teaching + Learning Lab*, *Information Systems and Technology*, and the office of *Open Learning* – came together to establish a common hub for resources and materials for instructors to support remote

[5] MIT Now: https://now.mit.edu

[6] MIT Covid Pass: http://covidapps.mit.edu

emergency teaching[7], with a complementary website for students to support their remote learning[8]. At the same time, the budget for the university's office of *Experiential Learning Opportunities* (ELO) was significantly increased, such that it was able to offer rapid funding to facilitate the delivery of remote course elements or activities that practiced 'learning by doing'.

Enabled by ELO funding, MIT has fashioned a response to emergency teaching that preserves the 'mind and hand' character of its education and hands-on experiential approach. While some 'design-build-test' and lab-based experiences were postponed, removed or replaced with online simulations, a surprising number were retained through, in the words of one university leader, "*mailing out kits of parts and have students build things at home*". It was estimated that, in Mechanical Engineering alone, kits were sent out to students in 16 separate courses during the 2020/21 academic year. Examples included the first year elective *Toy Product Design* (class 2.00b[9]) and the second year elective *Design and Manufacturing* (class 2.007[10], as outlined in Box 1). A range of mechanisms were put in place by the university to support the logistics of constructing and using these kits. As well as the establishment of a dedicated on-campus office for shipping materials to students, this included the launch of an online framework[11] to help students and instructors identify the level of risk associated with different hands-on activities undertaken from home. Where providing students with at-home shipping kits was not feasible, other approaches were used to re-create students' hands-on experiences. For example, the NEET *Advanced Materials Machines* and *Renewable Energy Machines* threads were combined into a shared introductory course, where students designed a machine online that was subsequently 3D printed and tested by instructors on campus. A number of interviewees went on to suggest that many of these remote experiential learning activities offered significant potential for scaling-up or franchising the approach to the benefit of leaners outside the MIT community and outside the US.

When reflecting on MIT's approach to emergency teaching as a whole, interviewees pointed to the progressive improvement in the quality of the online provision, from April/May 2020 when "*what we delivered wasn't even close to being great*" to the courses offered in the spring of 2021. Three elements of this progressive improvement appeared to be key.

The **first** was an improvement to MIT's digital learning infrastructure, facilitating greater flexibility in online teaching and learning. While MIT's innovations in massive open online courses (MOOCS) through *MITx*[12] have been world-leading, the infrastructure for supporting many of its residential undergraduate programmes lagged behind. Within weeks of the online pivot, a suite of online tools such as *Zoom*, *Panopto*, *Slack*, *Piatsa* and *GradeScope* were introduced. By October 2020, MIT had also replaced its 'homegrown' learning management system, *Stellar*, with *Canvas*.

[7] Teach Remote: https://teachremote.mit.edu

[8] Learn Remote: https://learnremote.mit.edu

[9] 2.00B: Toy Product Design: http://meche.mit.edu/featured-classes/toy-product-design

[10] 2.007: Design and Manufacturing I: https://me-2007.mit.edu

[11] MIT Remote Making resource site: https://wikis.mit.edu/confluence/display/make/Remote+Making

[12] MITx Massive Open Online Courses: https://openlearning.mit.edu/about-mitx

Box 1. Remote delivery of 2.007: Design and Manufacturing, Spring 2021

2.007 is an iconic course that exemplifies MIT's apprenticeship model of education, where instructors, in the words of the course co-lead, "*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 the course, students design and build their own machine. At the end of the semester, 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.

The online pivot to emergency teaching came mid-way through the spring 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, one at a time. 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 any questions students may have.

2021 'game board' sent to students in flat-pack form within their kit

The **second** element was to clarify the information given to students about their courses. For the 2020/21 academic year, MIT called upon instructors to prepare courses for a range of different delivery 'scenarios', including fully online as well as blended and hybrid modes, that could be rolled out depending on the COVID-19 restrictions in place. This led many instructors, in the words of one interviewee, "*to go back to first principles*" to reconsider the core learning goals and outcomes for their courses before identifying "*how do we meet these in a different way*", depending on the scenario taken. This refinement and articulation of the course objectives provided students with greater clarity over the expectations and structure of their classes, allowing them to better plan and manage their time.

The **third** element of the change was an increased adoption of student-centred pedagogies. Soon after the online pivot, it became apparent to many instructors that fostering student engagement would be a major challenge, and one which would not be combatted by simply posting recorded lectures online. As a result, and guided by a suite of workshops and webinars provided by the university[13], increasing numbers of faculty redesigned their courses into "*really top quality MITx style online sequences*" to support student-centred learning. These included, for example, interspersing short lectures with discussion-based problem-solving, polls to canvas students' ideas and responding to students' questions in the 'chat' function of Zoom. Even after MIT moved away from the mandatory 'pass/no record' system in the spring of 2020, many instructors opted to introduce formative assessments, such as quizzes with regular feedback, in place of mid-term examinations. Feedback from undergraduates suggested that this reduction in the use of summative grading had, in many cases, helped to build their intrinsic motivation and enable deeper learning. In the words of one student:

> *"The pass/fail system is one of the good things that's come out of the whole situation. It shifted the mindset from like 'what do I need to do to get an A in this class?' to 'all right, how do I maximise my learning?'... it completely changes the dynamics of the class. If everyone's there knowing that they are going to pass, they can put that aside and actually learn. I think that's really exciting".*

2.3. Addressing the challenges of emergency teaching

When describing the challenges faced during the period of emergency teaching at MIT, interviewees pointed to a range of issues, such as the difficulty of scheduling classes across multiple time-zones, facilitating whole-class discussion sessions, arranging the delivery of hands-on kits to students outside the US, and the impact of 'Zoom fatigue' on students and instructors alike.

However, for almost all interviewees, one challenge stood out: that of fostering student-to-student collaboration and peer learning in an online setting. While collaborative and group activities are embedded in courses across MIT's undergraduate curriculum, where peer learning has been most prominent is in informal interactions, fostered independently by students. The MIT campus has historically played a central role in facilitating these interactions, be they ideas arising from 'drop-in' events (often accompanied by free food), collaborations emerging from hands-on projects, or informal

[13] Preparing to teach remote: Spring 2021 semester: https://tll.mit.edu/preparing-to-teach-remote-spring-2021-semester/

mentorship fostered in shared spaces (such as common-rooms, dorms, labs and maker-spaces). Following the online pivot and move off campus, opportunities for such informal interaction were suddenly reduced and concerns were raised about the impact this would have on students' peer-learning and communities of support.

In response, the university sought to recreate, in the words of one interviewee, "*the lost opportunities for engagement*" while students were away from campus. Particular attention was paid to Psets: the university's 'Problem Set' homework assignments often tackled by students in informal study groups. Following the online pivot, students had struggled to identify, and interact with, peers for synchronous working on Psets. MIT established a number of innovations to foster such collaboration remotely. This included launching websites[14] that allowed students to identify and connect with peers who were tackling the same Pset at any point in time, and a scheme to loan all MIT students an iPad and Apple Pencil that could be used as a virtual whiteboard to facilitate ideas sharing and collaboration. Other mechanisms were also put in place to build students' networks and community remotely, both within and outside the curriculum. So, for example, within NEET, a suite of new online social events was established, a team-based learning component was embedded into every class (if one was not already in place) and plans are underway to engage the full MIT community in a new end-of-semester showcase event for selected NEET projects.

Despite these innovative interventions, interviewees noted that many elements of students' face-to-face collaborations could not be replicated online. What was missing in particular were the 'unscripted' interactions. It was noted that, 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. 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".*

Almost every interviewee spoke at length about the centrality of these 'serendipitous' in-person student interactions to MIT's educational culture and the challenges associated with fostering equivalent interactions remotely. Interviewees characterised these interactions as "*accidental*" and "*low stakes*", bringing no fixed agenda or planned outcome. In particular, students spoke at length about "*the lovely tradition of upperclassmen helping out the underclasses that is passed on to every new generation*" at MIT, which, again, were often seeded from these unplanned on-campus connections. While considerable effort has been devoted to recreating these types of interactions online – for example through peer-to-peer mentorship programmes or through the establishment of 'virtual dorm rooms' to connect students who would have been co-housed in dormitory corridors – students characterised them as "*very planned, very intentional; sterile isn't the right word, but something is missing somehow*".

[14] Websites include Explain.mit (https://explain.mit.edu) and Pset Partners (which requires an MIT student ID to access).

While this was a loss keenly felt by students and instructors alike, interviewees also suggested that one compensation had come in the form of a new connectivity forged across instructors and students since the start of emergency teaching. They pointed to a number of indicators of this connectivity, including the increased use of faculty 'office hours'. Contrasting their experience prior to March 2020, many noted that faculty had "*really got to know each of the students*" in these sessions, which often moved beyond purely technical questions into broader discussions about students' 'home life'. In addition, soon after the online pivot, MIT established the *Student Success Coaching Program*[15], in which students were offered one-to-one weekly coaching sessions to identify problems, offer support and enhance their capacity for distance learning. Five hundred and fifty staff, administrators and instructors volunteered to become coaches for this programme. Not only did this offer individual and personalised support for MIT students, it fostered new networks across the community of coaches. Indeed, many interviewees described how the experience of emergency teaching had brought together administrators, instructors and support staff, across functions and organisational hierarchies, to establish new communities of practice around teaching and learning. Many went on to speak about their pride in the university's response to COVID-19 and the connectivity, common purpose and 'espirit de corps' it had fostered across the MIT community. Speaking for many, one interviewee simply said: "*I have never felt so proud to say that I work at MIT*".

3. Impact of emergency teaching on MIT's educational approach

When asked to reflect on the legacy of emergency teaching on MIT's engineering education, some noted that it was "*still too early*" to determine its longer-term impact. Instructors and students were still living through it: "*everyone has been keeping their nose above the water… the synthesis that's needed has not yet been done*". For those looking beyond the COVID-19 emergency, the first priority for most was to re-establish the university's distinctive on-campus culture. As one interviewee put it, "*getting the energy back and the vibrance and the curiosity"* by reconnecting with peers in a face-to-face environment.

However, looking longer term, feedback suggests that the experience of emergency teaching was likely to impact the MIT's education in two distinct ways.

The **first anticipated impact** was on the pedagogical practices of instructors. The experience of re-designing courses for online delivery had led some instructors to fundamentally review their learning goals and increase their adoption of student-centred and blended learning. It was suggested that many of these attitudinal and pedagogical changes were likely to be permanent. In reflecting on the impact of emergency teaching, 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*

[15] MIT Student Success Coaching Program: https://covid19.mit.edu/undergraduate-students-student-success-coaching-program

> *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 when we return".*

The **second anticipated impact** was through identifying new opportunities to enhance global connectivity and off-campus experiential learning for MIT's students. In the words of one university leader, "*the pandemic has taught us that it's easier to do these things than we thought*". Many of the practices described are likely to be incorporated permanently into MIT's educational approach. For example, the introduction of world experts as guest speakers into classes using video conferencing was seen as an innovation that would become standard practice at the university. New opportunities are also apparent in the cooperative design and delivery of large-scale courses that bring together MIT instructors and students with peers from other universities across the world.

In addition, the experience of emergency teaching opened up new avenues to broaden students' learning experience. Historically, one of the major barriers to increasing the external and global exposure of MIT students has been their reluctance to leave campus. Take-up for off-campus experiences such as semesters abroad or internships has long been low. The online pivot pointed to opportunities to overcome students' concerns by offering experiences that blend off-campus experiential learning with continued connectivity with MIT. A significant minority of MIT students engaged with emergency teaching by forming 'pods', typically of 6–10 individuals, and renting a shared residence close to their home region. Feedback suggests that the ability to collaborate and engage in face-to-face peer learning within these pod groups provided students with a more positive learning experience than those who engaged with their courses while living alone or within family homes. Interviewees suggested that the key difference was that the pod groups were able to "*preserve the pieces of the campus experience that are important to students, which is to bring their friends with them".* The pod model was seen to offer considerable potential for engaging students in immersive, experiential opportunities off-campus – such as in public service, the voluntary sector or in start-ups – as part of a peer MIT group where "*they still had enough MIT connection to make it worthwhile*".

However, when reflecting on how the legacy of COVID-19 emergency teaching might influence the future of MIT's education, most interviewees suggested that another factor was likely to have an even more profound impact: the US-driven movement for racial equality. It was consistently noted that the most passionate and far-reaching conversations across the MIT community centred around diversity, equality and inclusion (DEI). While the experience of emergency teaching will undoubtedly influence the modalities and mechanisms used to deliver to MIT's mission, it was suggested that the movement for social justice was likely to influence the university's core values and was therefore the one more likely to trigger enduring cultural change. In the words of one university leader:

> *"The place where I am seeing different attitudes emerge is in the DEI space. I think that has moved the needle more than COVID… We have always taken pride in the diversity of the student body, and I think that what has come out this year is that that's probably not enough… people are thinking about how can we be deliberate in moving that needle and playing a leadership role in that space".*

This priority given to DEI is evident in recommendations emerging from a taskforce launched by MIT's President in July 2020. The *Task Force 2021 and Beyond*[16] was established to examine the lessons learnt from COVID-19 and chart a future direction for MIT. One of the Taskforce groups was charged with examining MIT's education. At the heart of its recommendations is a call for MIT to educate the 'whole student'. They note that:

> *"Such an education should help students to both take ownership of their lives and beliefs and listen carefully to new ideas and different perspectives that reaffirm, or help them to reimagine, what they believe is true and right and just. A focus on the whole student also recognises that well-being, satisfaction, and engagement are entwined throughout college and life".*

To enable such an approach, the education Taskforce group proposed mechanisms to help students "*recognise and engage critically with the structural, systemic and institutional hierarchies that shape our professional, civic and personal lives*". Additional recommendations made by the education group included: nurturing students' 'experiential empathy' for addressing regional, national and global societal challenges through engaging them in immersive experiential learning opportunities outside MIT; exploring new opportunities to advance 'unscripted' student interaction and collaboration in a remote or online setting; developing new mechanisms to support life-long learning across the MIT community; and realigning institutional incentives to better support and reward teaching excellence.

Taken together, the university's engagement in DEI and its commitment to harnessing the lessons learnt from COVID-19 point to an reinvigoration of its distinctive educational philosophy. These two developments appear to be coming together in a reaffirmation of MIT's 'mind and hand' approach to educating tomorrow's engineers.

Source of evidence

The case study for MIT (including Part A, the review of the Design Challenge One in the Systems Design & Management (SDM) programme, and Part B, this review of the 'institutional context') drew upon one-to-one interviews with 22 individuals: the Associate Dean of Engineering; the university Vice Chancellor; the Dean for Digital Learning; the Director of the Teaching + Learning Lab; the Executive Director of NEET; the NEET curriculum designer; two faculty members (and instructors from 2.007); the Executive Director of the SDM programme; the Academic Director of the SDM programme; three Teaching Assistants from SDM; three SDM students; five engineering undergraduates and one Councillor from the City of Cambridge.

Further information about the methodology for development of CEEDA case studies is given at the project website[17].

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

[17] CEEDA case study structure and approach: https://www.ceeda.org/about#case-studies

Aalborg University, Denmark

Case Study Part A – Best Practice Activity

Giraf project

Student cohort:	**60**
Location:	**100% online (after 6 weeks)**
Duration:	**1 semester (4 months)**
Date delivered:	**Feb-May 2020**
Activity type:	**Curricular project**
New/existing:	**Existing activity**
Hands-on element:	**Code development**
Cross time-zones:	**No**

Distinctive feature of case study

Exposing students to uncertainty and complexity in their problem solving

Abstract

Activity overview

Giraf is a group project for students to develop an app for autistic children experiencing profound language barriers. Taking a highly student-led approach, it requires the full cohort of 60 students to work together on the app's development: students themselves must organise the cohort into a network of inter-dependent teams and manage their collaboration and app development throughout the semester. The app has been progressively advanced by each new year-group of students enrolled in the project; incoming cohorts are asked to assess, refine and build upon the existing code developed in the previous year.

Independent review

The Giraf project exposes students to complexity in two dimensions: in team organisation (the cohort-wide network of groups must work together to deliver a single product) and in problem construction (students must advance and improve an existing product, rather than start from a blank slate). The move to online 'emergency teaching' early in the semester was seen to amplify existing challenges faced by students engaged in the project with respect to intra-cohort collaboration.

Activity details

Giraf is a group project taken by undergraduate Software Engineering students in their third year of study. As with all group projects at Aalborg University, students dedicate half of their curricular time to the project, which lasts for a full (four-month) semester. At the project launch, students are provided with access to the existing code, advice from the previous year-group and an introduction to the 'customers': teachers at local specialist schools for children with autism. The focus and structure of much of the rest of the four-month project is almost entirely led and directed by the students themselves.

1. Activity overview

Giraf is a group project for Software Engineering students to develop an app for autistic children experiencing profound language difficulties. The project is designed to simulate the conditions, constraints and interdependencies of a real-life software development project, with a real world client.

The Giraf app (standing for Graphical Interface Resources for Autistic Folk) is designed to help autistic children manage their daily routines and provide them with entertainment. Since its establishment in 2011, the app has been progressively advanced by each new year-group of students enrolled in the project; incoming cohorts are asked to assess, refine and build upon the existing code developed in the previous year.

To determine the priorities for the app's development, students must gather and review feedback offered by two groups. The first group is the previous year-group of Giraf students, who provide a report and oral presentation on the strengths and weaknesses of both the code they developed and their approach to the project's management. The second group is the project 'customer' – teachers and speech development therapists from a local school and kindergarten for autistic children – who offer advice on the constraints of the existing app and priorities for future development.

The entire cohort, comprising around 60 students, is required to work together to produce a working app at the close of the semester. The faculty member coordinating the project intentionally offers minimal scaffolding and guidance to the cohort, to allow the product development and project management to be almost entirely student-led. While regular group facilitation is provided, the students must self-organise into operational teams and manage the process of the app's development, testing and delivery themselves. In recent years, and based on advice given by previous year-groups, students have typically adopted an 'Agile' management approach. Guided by this approach, students formed a network of interconnected groups: one group interfaced with the customer, one group managed the project and the remaining groups developed different aspects of the code.

Reflecting authentic software development practices in industry, Giraf students are dependent on others to ensure the successful completion of the project: dependent on the work of previous student year-groups and dependent on the work of other groups. A number of interviewees noted that this interdependence is critical to building students' adaptability and resilience in their problem-solving: *"everything they do when they leave here is dependent on other people, there is uncertainty. That acceptance of being part of a network of people that are co-creating is part of being both adaptable and resilient*".

Emergency teaching was introduced at Aalborg University in March 2020, six weeks into the spring delivery of the Giraf project. For the initial six weeks, the students worked face-to-face within their project rooms; thereafter, all work was conducted online. The student-led nature of the project meant that very few changes or interventions were put in place by faculty to support this transition: students were expected to navigate and manage the online pivot with minimal external support.

2. Independent review

2.1. Distinctive features

The feature that sets the Giraf project apart from peer problem-based learning (PBL) experiences worldwide is the level of complexity and uncertainty students encounter as they tackle this activity.

Giraf forms one element of a wider drive at Aalborg University to broaden and strengthen students' PBL Competencies[1] as they advance through their studies, progressively exposing them to projects and problems of increasing complexity and interdisciplinarity. As illustrated in Figure 1, it starts with engagement in 'single discipline' projects (as shown in the lower left quadrant) in the early semesters of their undergraduate degree, and incrementally introduces variations in the types of projects and/or problems they are asked to tackle. As Figure 1 indicates, complexity can be introduced in (i) interdisciplinarity; and/or in (ii) complexity of team or problem construction. The building of complexity culminates with an opportunity for students to participate in one or more MegaProjects: complex projects that are tackled by interdisciplinary networks of teams. 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.

Giraf is scheduled at a mid-point in the combined bachelor and master Software Engineering programme. As such, it represents a stepping stone in the incremental progression in students'

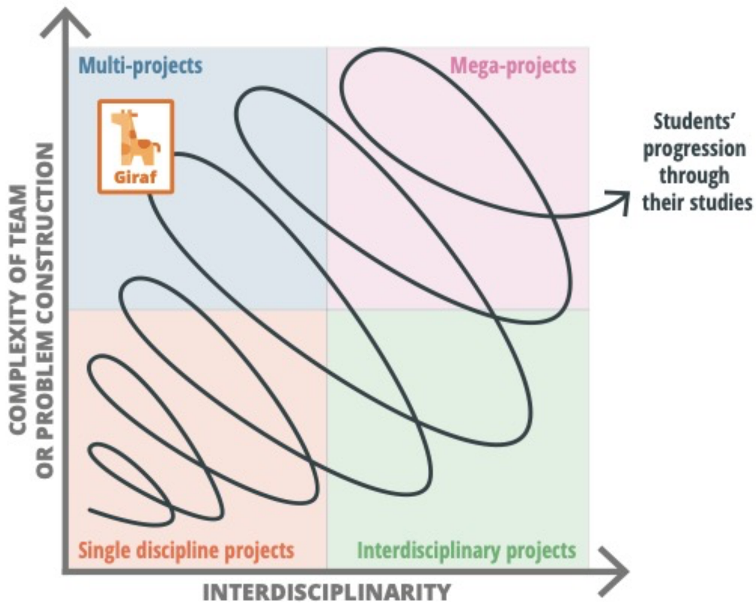

Figure 1. Variation in project interdisciplinarity and complexity as students progress through their studies

[1] The PBL Competencies are divided into four interrelated categories: **problem-oriented competencies** (relating to students' ability to identify, analyse, formulate and solve authentic problems); **interpersonal competencies** (relating to students' ability to collaborate in problem-based work, including relationships internal and external to the group); **structural competencies** (relating to students ability to organise and manage problem- and project-based work); and **metacognitive (or reflective) competencies** (relating to students' ability to reflect professionally on the learning process itself).

exposure to project and problem complexity. It is characterised within Aalborg University as a 'multi-project': while it only spans a single discipline, Giraf exposes students to complexity in two dimensions:

- **complexity in problem construction:** students do not start their project from a blank slate at the start of the semester. Instead, they must develop, redesign and restructure existing code, as provided by the previous year-group of students that worked on the Giraf app.
- **complexity in team organisation:** the full student cohort must work together, as a network of groups, to deliver a single product. The construction and management of these groups must also be organised by the students themselves such that, by the close of the semester, they deliver a working product that meets the needs and constraints of a real client.

2.2. Success factors

One of the most striking features of the Giraf project is the extent to which it is almost entirely student-led – organised and managed independently by the students – despite the complex nature of the problem and project construction. Although communication challenges were apparent (see Section 2.3), the pivot to emergency teaching did not derail the project's progress or delivery. The resilience of the students and the project's design to this online pivot appeared to be underpinned by three factors:

- **students' PBL experience and training:** the Giraf project builds upon students' training in PBL and two prior years (four semesters) of increasingly complex projects. Interviewees suggested therefore that students came to the project, and the online pivot, with an important skill set already in place: they had confidence in and a familiarity with strategies both to define and analyse problems and to manage multi-faceted projects. Such competencies were understood to facilitate students' capacity to translate the principles to a new, in this case online, setting.
- **learning across year-groups:** since its launch in 2011, the Giraf project coordinator has refined its structure and design to maximise students' autonomy. With iterative reductions in the project's scaffolding came an increased focus on learning from the experience of foregoing cohorts: encouraging students not just to build on the code developed by previous year-groups, but also to take on board their lessons learnt in the project's management. The robust approach taken by the 2020 cohort, and its resilience to the pivot online, undoubtedly benefitted from this inter-year-group advice and experience.
- **student engagement and connectivity:** a number of factors that boosted students' commitment to the Giraf project also appeared to help sustain engagement beyond the online pivot. For example, the Giraf project has long been viewed by students as a mechanism to broker new inter-cohort networks. Following the online pivot, where students were otherwise physically isolated from peers, the opportunity to foster such connectivity was therefore particularly valued. Student engagement was also clearly strengthened by the authenticity of the experience, both through developing a solution to a real social need and through working within a team environment that mirrored those they would likely encounter in industry.

2.3. Challenges faced

The major challenge experienced by Giraf project students, be they engaged face-to-face or online, is that of collaborating effectively across the network of groups. Prior to the online pivot, all Giraf students were co-located in a single corridor on campus, working for much of the day within dedicated group project rooms. Despite working face-to-face in these shared spaces, each new cohort would experience what was termed "*a steep learning curve*" as they built the competencies needed to navigate the intra-cohort relationships. The pivot online in March 2020 was noted to amplify these challenges, particularly within the three major routes for intra-cohort collaboration, as outlined below:

- **scheduled meetings:** in recent years, and based on the Agile management method, scheduled meetings have been held for the full cohort at the beginning and end of each one-month 'sprint' (or development period). These meetings are designed to allow students to present and discuss progress, issues and future plans. When held face-to-face, it was noted that the cohort would often "*naturally drift into sub-groups to have side conversations*" around particular issues or ideas raised in the meeting. Moving such large-scale meetings online proved problematic. Online presentations 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. Identifying common themes of interest arising from these group discussions also proved difficult, as did sub-dividing students by interest theme in online 'break-out sessions'. As a result, online meetings often became "*long and quite boring*" and structured around a sequence of presentations, with most students playing a passive role.
- **ad-hoc meetings:** prior to the online pivot, students would simply "*knock on the door*" of peer groups to ask questions or exchange information as and when issues arose. Following the move online, these interactions were typically replaced with scheduled meetings (which often postponed the exchange) or requests were relayed via brief text messages. These online interactions were often characterised as being transaction: "*it would be formal, straight to the point*". The use of text messaging in particular was also understood to be the source of some misunderstandings and inter-group conflict which affected some cross-group relationships.
- **informal and social interactions:** intra-cohort networking and social interactions have long played a key role in the Giraf project, with 'release parties' at the end of each 'sprint' becoming a regular fixture. The online pivot put pressure on these informal interactions. Although some intra-cohort social gatherings were attempted via Discord, the practicalities of bringing together 60 people on a single call led to what was described as "*forced and unnatural*" interactions which many students soon abandoned.

Many of these challenges remained unresolved throughout the project. However, student interviewees noted that their subsequent reflections on these issues would allow them to offer robust advice to future cohorts that were engaged online. Their major piece of advice was to engage with peers in regular face-to-face video calls, within and across groups, rather than rely on voice calls or text chats.

3. Activity details

Giraf is a group project taken by Software Engineering students in their third year of study. As with all group projects at Aalborg University, students dedicate half of their curricular time to the project, which lasts for a full (four-month) semester.

At the time of writing, the Giraf project has been delivered twice since 'emergency teaching' was first introduced at Aalborg University: once in February 2020 and once in September 2020. On both occasions, student groups were initially able to work together face-to-face (albeit under social distancing conditions) within dedicated project rooms before all operations were pivoted online mid-way into the semester. Both cohorts of students therefore had the opportunity to meet and interact face-to-face before group working moved online; all subsequent interactions were remote.

3.1. Structure of the activity

As summarised in the table below, the four-month project was delivered in three broad phases. Phases 1 and 3 (focused respectively on introducing the project and assessing its outcomes) were the only elements of the activity that were pre-set by the project coordinator. These only occupied the first week and final two weeks of the project. Phase 2 (comprising the planning, development and delivery of the Giraf app) was almost entirely student designed and led.

Phase 1 Weeks 0–1	**Project framing** In the first few days of the semester, the Giraf project coordinator provided students with an introduction the project's focus, objectives and final deliverables. As is standard for group projects at the university, the cohort was then asked to self-divide into groups of roughly six. It should be noted that, although the group membership was agreed at this stage, the roles assumed by each group were not yet determined. The project coordinator provided students with access to the existing code for the Giraf app, the project web-page and all group project reports from the previous year group; each student was encouraged to read at least two of these reports. Two sets of contextual presentations were then delivered to the cohort: • from the representatives of the previous year-group who participated in Giraf: these representatives outlined the progress made by the year group and described the current status of the app (including any omissions and errors in the code). They also offered advice on how the new student cohort might manage the project; • from the 'customers' (representatives from local specialist autistic schools): they outlined the daily routines of their children; the strengths and weakness of the existing Giraf app and their priorities for its future development. The project coordinator then made clear that (apart from weekly group supervisions) the project thereafter would be entirely student-led and managed. The cohort was subsequently left alone in the lecture room to decide the project's next steps.

Phase 2 Weeks 1–14	**Project planning, development and delivery** Taking advice from the previous year-group, the 2020 Giraf students decided to adopt an Agile management approach. This called for specific roles to be allocated to each group. This included one 'Product Owner' group (to interface with the customer and convey their needs and priorities) and one 'Scrum Master' group (to support the development team and cross-group communication). All other groups were allocated various coding roles in the app's development. In line with the Agile approach, the four-month project was divided into four discrete month-long 'sprints'; for each sprint, the cohort agreed specific development goals and subsequently developed, tested and released the updated app. The first of these sprints focused primarily on rectifying any errors in the existing code. Subsequent sprints focused in areas such as improving the project documentation and prototyping a new communications function for the app. The cohort also agreed the protocol for scheduled meetings: a daily meeting for each group, a weekly meeting that brought together one representative from each group, and a meeting at the beginning and end of each 'sprint' for the full cohort. Additional ad-hoc meetings would also be held between groups as needed. After the online pivot, most meetings were held using Discord voice chat. The Product Owner group also met regularly with customers to capture their priorities, discuss developments and undertake useability testing of the app (which was conducted via Zoom calls, using a 'screen share' function).
Phase 3 Weeks 14–16	**Finalisation of group project report and assessment** In the final two weeks of the project, each group focused on completing their project report, which was used to inform the subsequent oral exam (see Section 3.4). Each report contained a chapter offering advice to the next year group of Giraf students.

3.2. The brief and the deliverables

The brief given to students at the start of the semester was "*to create free software for people with autism that works as a communication tool and as a teaching and entertainment environment. The project should be available on all relevant platforms*". By the close of the semester, the student cohort as a whole was asked to deliver a functional product.

Each group was also asked to produce a report charting their activities, achievements and reflections on the project. Group reports were required to contain:

- one chapter outlining the role of the Giraf project in their undergraduate studies;
- one chapter per development cycle (or 'sprint') documenting the stages of analysis, design, refactoring, implementation and testing;
- at least one 'topic' focused chapter, in areas such as project management, useability or prototyping;

- one chapter outlining the groups' reflection on their project learning, including advice for future year-groups of students.

3.3. Learning goals/objectives

The project goals, as stated in the study regulations[2], are: "*that the student acquires knowledge of and skills in analysis, design, implementation and assessment of complex software systems in a larger development environment*".

Supporting this overall goal are learning objectives centred on three domains, as listed below:

- ***knowledge:*** *document knowledge of and overview of key techniques in the work of developing software that solves realistic problems;*
- ***skills:*** *analyse, design, program, and test applications that are part of a complex organisational environment;*
- ***competencies:*** *delineate and implement a solution to part of a major software development problem using appropriate techniques.*

3.4. Team and cohort assessment

In line with all group projects at Aalborg University, the Giraf project was assessed on the basis of a group oral exam, from which each student was assigned an individual grade. The oral exam drew heavily on the report written by the group, and asks students to explain, validate and reflect upon both what was written as well as their experience during the project.

Oral exams were undertaken with all group members assembled together with their supervisor and an external examiner. Each group member first gave an individual 10-minute presentation on their project from a common slide deck shared by all group members. This was followed by approximately four hours of discussion, with breaks, where the examiners addressed questions to the group members. The maximum duration of the oral exam equated to 45 minutes per student. Special dispensation was given to hold oral exams at Aalborg University in person in June 2020.

3.5. The teaching team

The teaching team comprised:

- the project coordinator, who designed and developed the Giraf project;
- six project supervisors, each supporting up to three groups via weekly supervision sessions;
- the project 'customers': teachers and speech development therapists from a specialist school and kindergarten in the Aalborg Municipality.

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[2] Giraf project study regulations (in Danish): https://moduler.aau.dk/course/2018-2019/DSNSWB601?lang=da-DK

3.6. Participants and project groups

60 students participated in the Giraf project in the spring of 2020, working in 13 groups. As described in Section 3.1, two groups assumed project management roles (that of the 'Product Owner' and 'Scrum Manager'), with the remaining groups working on code development.

Participants were third year students enrolled in the Software Engineering programme at the university.

3.7. Technology used

The following applications and technologies were used in the 2020 Giraf project:

- project information (such as the schedule and study regulation) was housed on a Moodle system;
- a dedicated wiki (GIRAF Wiki[3]) was used to organise the code development and provide background information for project groups;
- building on the existing code, the Giraf app was developed in Flutter (Dart) with the backend written in C#;
- group interactions with supervisors and customers moved from MS Teams to Zoom mid-way through the semester, following the university's decision to make Zoom its approved video conferencing software;
- students chose to use Discord for communication within and between groups. Many groups kept their Discord voice channel open throughout the day, to allow groups-mates to interact and ask questions as and when they arose;
- students also chose to use Trello and GitHub to replace physical 'scrum boards' (the Agile approach to project management) for project organisation and to assign tasks to groups.

Source of evidence

The case study for Aalborg University (including Part A, this review of the Giraf project, and Part B, the review of the 'institutional context') drew upon one-to-one interviews with 13 individuals: the Vice-Dean of Education in the Technical Faculty of IT and Design; the Vice-Dean of Education in the Faculty of Engineering and Science; one department head; two research leaders from the UNESCO PBL Centre; three undergraduate students; one external collaborator from a specialist school working with the Giraf project; one project coordinator; and three engineering faculty. The interviews were conducted between November 2020 and February 2021.

Further information about the methodology for development of CEEDA case studies is given at the project website[4].

[3] GIRAF Wiki: https://aau-giraf.github.io/wiki/
[4] CEEDA case study structure and approach: https://www.ceeda.org/about#case-studies

Aalborg University, Denmark

Case Study Part B – Institutional context

Undergraduate engineering student intake (1st year cohort 2020/21):	**≈ 2000**
Number of engineering faculty:	**≈ 770**
Duration of undergraduate engineering degree (to BEng):	**3 years**

1. Defining features of Aalborg's engineering education

Since its foundation in 1974, Aalborg University has taken a distinctive problem-based learning (PBL) approach to its research and education activities. 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: supported by facilitators, students are expected to identify and define their problem, as well as manage and source the materials needed to deliver their project. Within the university's two Faculties of engineering and technology[1], most project groups are allocated a dedicated meeting room on campus for the duration of the semester where they are able to meet team mates and work on their project. The university's undergraduate PBL model is supported by the in-house UNESCO PBL Centre[2], whose research and ideas also have considerable impact across the wider engineering education sector.

In 2018, Aalborg's Faculties of engineering and technology[1] embarked on a major programme to reimagine their PBL pedagogy. In the context of a two-decade increase in student numbers, the vision is to set a new benchmark for engineering PBL that could operate at scale and equip graduates to tackle the complex interdisciplinary challenges facing society. The model combines a student-led, interdisciplinary and flexible approach with scaffolding that allows students to progressively build, practice and strengthen what are termed *PBL Competencies*[3] throughout their studies.

The implementation of the new PBL vision began in 2018 and many components were in early development or piloting when the university pivoted to online teaching in March 2020. Three inter-related threads are central to the reform, as outlined below, relating in turn to project variation, the nurturing of student competencies and digitisation of learning materials.

The **first thread** is to embed a progression in the complexity and interdisciplinarity of projects tackled by students throughout their studies. In the words of one interviewee, it 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

[1] The Technical Faculty of IT and Design; and the Faculty of Engineering and Science

[2] Aalborg Centre for PBL in Engineering Science and Sustainability under the Auspices of UNESCO: https://www.ucpbl.net

[3] The PBL Competencies are divided into four interrelated categories: **problem-oriented competencies** (relating to students' ability to identify, analyse, formulate and solve authentic problems); **interpersonal competencies** (relating to students' ability to collaborate in problem-based work, including relationships internal and external to the group); **structural competencies** (relating to students ability to organise and manage problem- and project-based work); and **metacognitive (or reflective) competencies** (relating to students' ability to reflect professionally on the learning process itself).

variety in both the construction of the project and complexity of the problem as their learning progresses. This might include, for example, variation in the projct duration, disciplinary scope, and structure of inter-team collaboration. This step-by-step progression builds from the first year of study and culminates with an option to engage in the newly-established MegaProjects[4] 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. While facilitated by an interdisciplinary faculty group, each MegaProject is coordinated and managed by the students themselves.

The **second thread** is to ensure that students are equipped to conceptualise, reflect upon and showcase the competencies developed as part of their problem-led education. Prior to the launch of the new PBL vision, all incoming engineering students were already participating in an introductory PBL course in their first semester of study to support the formation of their PBL Competencies[2] in areas such as collaboration, project management, and problem understanding. However, advancement of these capabilities beyond this point was understood to be largely tacit, with no formal mechanism to reflect upon or assess them at an individual student (rather than a group) level. As a result, some students were left struggling to conceptualise and articulate their relevant experiences and strengths to prospective employers and peers on graduation. To address this challenge, from the spring of 2021, all engineering students at the university are required to build a 'PBL Competency Profile'. At the completion of their studies, each students' PBL Competency Profile will provide a self-reflective analysis of their experiences, achievements and strengths; this portfolio, and the quality of self-analysis it contains, will be 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.

The **third thread** is to establish a digital learning infrastructure that facilitates flexible, student-led learning and problem-solving. This new infrastructure will help to support the remote team-working, communication, and project management that lie at the heart of the university's growing number of complex and interdisciplinary group projects. However, the major focus for these digital tools is to reshape the university's taught courses. Inspired by global best practices, the vision is to offer students the flexibility to access the information and learning resources needed to advance their group projects, as and when they need it. This thread of asynchronous digital material (offered as both core and elective modules) will be embedded within the taught courses, complementing the synchronous materials offered in blended and face-to-face modes. PBL Digital is one major initiative driving these reforms across the engineering disciplines. One of its early areas of focus is to support faculty to identify the best modality for delivery of each core component of their courses, be that via face-to-face, remote or blended learning.

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

2. Aalborg's experience of emergency teaching in engineering

2.1. Emergency teaching restrictions

Aalborg University pivoted all undergraduate programmes into a fully online mode in March 2020, a few weeks into their spring semester, with only the end-of-year examinations subsequently delivered in person. Since September 2020, the university's education has oscillated between a blended mode – where most classes were delivered online but students were often able to connect face-to-face in their project rooms – and a fully online mode. At the time of writing, in February 2021, the university had launched its spring semester fully online.

2.2. Managing the transition to emergency teaching

The university's initial online pivot in March 2020 was rapid. The lockdown came into effect within two hours of the Danish government's announcement, which left little time to make preparations or retrieve equipment from campus. The primary focus for the university at this time was simply the practicalities of translating its PBL curriculum online.

One distinctive feature of Aalborg's pedagogy is the range of modalities and interactions it supports: as well as components organised by instructors (such as workshops, lectures and end-of-semester oral exams for group projects), it embeds a significant number of components organised by students, particularly with respect to managing and progressing their groups project. While undoubtedly supported by the PBL Digital initiative, the logistics for transferring this complex range of learning modes into an online format was challenging and resource-intensive. As one engineering Pro-Dean noted: "*so much of our education is student-led, there are fewer one-size-fits-all courses and elements that can be transferred online than you would find in other universities*". This complexity is particularly apparent in the 50% of the curriculum dedicated to group projects. So, for example, in many universities worldwide, the experiments undertaken during 'engineering labs' are predetermined by instructors, with each groups' findings focused on a similar outcome and recorded in a similar form. In contrast, at Aalborg University, engineering labs are often used as a mechanism for students to advance their group projects, and therefore the goals and focus on any experimentation is determined by the group in question, with on-demand facilitation provided by technicians.

Despite these challenges, interviewees went on to note, with some surprise, that students' transition from face-to-face to online learning, particularly in the 'group project' half of the curriculum, was "*relatively painless*". They largely attributed this resilience to the students' training in PBL and experience of directing their own learning and self-managing their work. In the words of one university leader: *"PBL gives you two things: it's a pedagogical model for how you engage in problems, but it is also a very nice way to structure the student's working life… it gives the students a schedule… they were not waiting for the teachers to deal with [the impact of COVID-19]; they are used to taking their own responsibility*". This familiarity with self-directed group learning, however, was less apparent amongst one particular student population: the new cohort that started their studies in September 2020. Unlike those that pivoted online in March 2020, these students only had a few months' experience of PBL training and face-to-face problem-solving before the university again shifted into a fully online mode in December 2020. They also lacked the connectivity with peers beyond the groups formed for their first semester project, and therefore were less likely to benefit from broader student support networks.

At the time of writing, in February 2021, Aalborg University was entering its third semester of emergency teaching. It was noted by interviewees that, while faculty and students alike were "*exhausted, spending hour after hour at the computer*", each semester had heralded improvements and refinements to the university's online or blended approach. However, the university had undoubtedly benefited from the face-to-face start to its first two semesters of emergency teaching. The university's student-led process of team formation for group projects, as well as early bonding and expectation setting within these groups, had all been undertaken in this face-to-face period. At the time of writing, faculty were anticipating with some trepidation the impact of a fully online start to group projects, where team formation, orientation and bonding would all be undertaken remotely and students' interactions would not build upon an existing face-to-face relationship.

2.3. Addressing the challenges of emergency teaching

When reflecting on the challenges faced during 'emergency teaching', interviewees consistently spoke about the pivotal role that has historically been played by both the physical facilities and the face-to-face interaction of staff and students in the university's PBL approach. The dedicated project room allocated to each engineering student group was characterised as "*a personal space, a second home*" on campus which anchored students' shared learning experience. Students would typically spend much of their working day in this space, outside scheduled classes. Group learning and staff/student interaction in these spaces was also understood to be underpinned by tacit knowledge: "*through interacting, body language, eye contact*", which often guided the type and levels of facilitation offered by instructors.

With the reduction or removal of students' access to project meeting spaces, the pivot to emergency teaching was understood to "*put a lot more pressure*" on group project work. It precipitated a formalisation of some student-to-student and student-to-instructor interactions, which took place through pre-arranged meetings, rather than drop-in sessions or "*seeing someone in the corridor*". This issue was exacerbated by the increasing tendency of students to connect without web-cams switched on, such that peers and facilitators were unable to see their faces. Interviewees noted a number of consequences of this shift in students' modes of interaction. Some pointed to "*more conflicts than normal in groups… [where] students have a difficult time 'sensing' each other and being open about the challenge they have*". Others noted that, rather than working synchronously together, students often broke project tasks into discrete elements to be undertaken by individual students alone, and then "*assembled the project at the end, more like the approach they would have used at [high] school*".

Since the introduction of emergency teaching in March 2020, faculty and facilitators have employed a number of techniques to address these challenges. For example, some shifted group facilitation from a discrete activity (providing support during scheduled classes or sessions) to a continuous activity, "*as a constant presence*", 'checking in' on students regularly. It was also noted that the increasing use of instant messaging platforms, such as Discord, has supported peer-learning and the dissemination of information between students. Through these open 'chat' platforms, facilitators' feedback and responses to questions from one group can now be accessed by the entire cohort. As one interviewee noted, "*there was always a lot of repetition in the questions and answers which was not shared across groups… [now] channels are open. There is more openness in the way we share*".

The online pivot has also brought into sharp focus the major role played by students' informal, non-scheduled peer interactions to their learning and development. One interviewee described these as "*the informal chit-chat before the lecture or [walking] between buildings… interactions that create a community where they are learning together*". Prior to emergency teaching, such interactions were serendipitous and emerged as a natural consequence of students' shared learning spaces on campus. A major impact of online learning was the significant drop in such interactions, a loss that was felt deeply by many students. Reconstructing such serendipitous and informal interactions online is one of a number of research themes in digital PBL being advanced at Aalborg University.

3. Impact of emergency teaching on educational approach

Interview feedback made clear that, while the experience of emergency teaching is unlikely to change the direction of travel for engineering education at Aalborg University, it has undoubtedly advanced and accelerated many aspects of its new PBL vision launched immediately prior to the pandemic. As discussed below, this acceleration was seen to impact two areas in particular: faculty pedagogical culture and the 'stress testing' of key innovations.

The **first impact** of emergency teaching, as noted by interviewees, has been on faculty culture: on their attitudes to both pedagogical change and digital learning. Historically, much of the innovation and pedagogical research at Aalborg University has focused on the 'group project' half of the curriculum, which has been central to its leading profile in engineering education globally. While many innovative practices were apparent in the 'taught courses' half of the curriculum, there remained a heavy reliance on teaching-centred and lecture-based delivery. Given the impact and profile of the university's education overall, the case for systemic change to 'taught courses' did not always resonate with faculty, with many reluctant to dedicate time to converting courses into asynchronous learning materials.

As with many universities across the world, the pivot to emergency teaching required all Aalborg University faculty to convert their courses to an online delivery mode. Interviewee feedback suggested that the most far-reaching pedagogical shift triggered by this pivot occurred not amongst the existing educational 'pioneers' but amongst other faculty groups that had historically taken a more teacher-centred approach, particularly within the 'taught courses'. Amongst this group, the rapid shift online was understood to have precipitated "*a breakdown of the barriers for faculty's first encounter with* *designing and delivering online learning components*". As a result, it had significantly accelerated many of the changes planned under the PBL Digital initiative. Interviewees also pointed to a recognition amongst many in this group that online delivery laid bare some of the weaknesses of a teacher-centred approach: "*you cannot lecture for 45 minutes... sitting and talking into a screen for 45 minutes online is awful, you need to have more interaction*". In response, a core group of faculty started to adopt new approaches to activate and engage students, breaking up classes using interactive and peer learning, often in break-out sessions.

While the rapid changes made to accommodate emergency teaching in March 2020 may only have been considered a temporary solution, interviewee feedback suggested that, after three full semesters of emergency teaching (at the time of writing), many of the changes made to enable blended and student-centred learning in the 'taught courses' are likely to be retained permanently. This is understood to have accelerated the university's plans to establish a much closer alignment between 'taught courses' and projects, whereby students are able to access asynchronous digital materials as and when needed to help them address challenges or new ideas in their group projects. Nonetheless, it was also acknowledged that some of the digital material developed in 2020 "*was a digital replication of what was [previously] developed in analogue"* and therefore considerable revision and development will be needed through the PBL Digital initiative to improve their quality and impact for future use. Despite this challenge, interviewees concluded that a new emphasis on digital learning was here to stay. In the words of one, "*we are never going back face-to-face. We were not there before [at Aalborg], but it will go more so, more balanced, more blended*".

The **second impact** of emergency teaching, as suggested by interview feedback, has been the opportunity to 'stress test' a number of components of the university's new PBL vision. Many of these pilots and advancements rest on the university's growing digital learning infrastructure and parallel research undertaken by the UNESCO PBL Centre. For example, emergency teaching has turned a spotlight on the potential offered by remote collaboration and online project management for the suite of the university's new complex group projects. Indeed, since March 2020, three MegaProjects have been supported, managed and delivered almost entirely online. Interviewee feedback also suggested that the rapid development of digital materials is also paving the way for other advancements at the university, such as micro-credentialing and the development of MOOCs for external audiences.

Emergency teaching also showcased the significant potential for projects that connect students and external collaborators from across the world. In the words of one interviewee, "*the idea of having students not physically in the country for a course is now a possibility in a way that it was not 6 months ago*". What has proved critical to the engagement of a geographically dispersed community has been the flexibility offered by the university in the ways in which projects are developed and delivered: flexibility, for example, in the scheduling and course credit allocation for projects or in the sequencing of learning objectives. Interviewee feedback suggested that such ongoing flexibility from university managers will play a central role in facilitating future bottom-up faculty innovations, beyond the current period of emergency teaching.

Source of evidence

The case study for Aalborg University (including Part A, the review of the Giraf project, and Part B, this review of the 'institutional context') drew upon one-to-one interviews with 13 individuals: the Vice-Dean of Education in the Technical Faculty of IT and Design; the Vice-Dean of Education in the Faculty of Engineering and Science; one department head; two research leaders from the UNESCO PBL Centre; three undergraduate students; one external collaborator from a specialist school working with the Giraf project; one project coordinator; and three engineering faculty. The interviews were conducted between November 2020 and February 2021.

Further information about the methodology for development of CEEDA case studies is given at the project website[5].

[5] CEEDA case study structure and approach: https://www.ceeda.org/about#case-studies

SUTD, Singapore

Case Study Part A – Best Practice Activity

Virtual Ideation Challenge

Student cohort:	**58**
Location:	**100% online**
Duration:	**2 days, full-time**
Date delivered:	**June 2020**
Activity type:	**Extra-curricular**
New/existing:	**New activity**
Hands-on element:	**No**
Cross time-zones:	**No**

Distinctive feature of case study

External collaboration to provide authentic context for learning

Abstract

Activity overview

Teams of students – with guidance from technical and clinician mentors – were tasked with developing technological solutions to challenges faced by Singapore in its fight against COVID-19. Designed and delivered in collaboration with clinicians from a local hospital, the activity gave students a unique immersion in a real-life public health challenge.

Independent review

The success of the activity was underpinned by the long-standing collaboration between SUTD and a local hospital as well as by the technical and clinical mentorship offered to teams. As an online activity, it enabled synchronous engagement of clinical mentors in a way that would not have been possible face-to-face.

Activity details

A two-day extracurricular challenge, newly established for 2020, that was open to any current or incoming SUTD undergraduate. Delivery was 100% online and 100% synchronous. Teams developed their solutions using story-boarding and/or 3D modelling; no physical prototyping was involved.

1. Activity overview

The Virtual Ideation Challenge (VIC) was a two-day extracurricular activity where current and incoming SUTD undergraduates connected with clinicians from a local hospital to tackle key technological challenges under the theme of "*reimagining healthcare in the time of COVID-19*".

Held over a weekend in June 2020, the VIC was a 100% online activity delivered as a partnership between SUTD and a team of clinicians from the COVID-19 response team at Changi General Hospital (CGH), an academic medical institution serving a community of more than one million people in eastern Singapore. Participating students – from across all SUTD disciplines and academic years – were divided into teams, with each tackling one of 14 'case scenarios' devised by the CGH clinicians. The scenarios described 14 challenges faced across the three major phases of the clinical and public health response to COVID-19 in Singapore: pre-pandemic (preparations for a pandemic); ongoing pandemic response (pandemic response); and post-pandemic (the 'new normal').

The opening session on the first day introduced students to the context for the VIC. It included webinars from CGH clinicians, as well as videos and a 360º interactive tour of the CGH Emergency Medicine department, CGH wards and migrant workers' dormitories, the latter of which saw the rapid spread of COVID-19 in the early weeks of the pandemic. From there, the VIC took a highly structured approach to guide students step-by-step through a design and ideation process over the two days. Online support, mentorship and facilitation for the student teams was provided by a group of graduate mentors and CGH clinician mentors. At the close of the two days, teams presented their design-thinking process and proposed the solution to their assigned challenge arising from COVID-19 to a judging panel via a five-minute online pitch.

2. Independent review

2.1. Distinctive features

Although the VIC incorporated a number of innovative features – such as the inclusion of incoming (yet to matriculate) as well as current SUTD undergraduates – one feature sets the activity apart overall: the active engagement and collaboration with external partners. The VIC was designed and delivered in close partnership with clinicians at a local hospital (CGH). Interviewee feedback made clear that the unique immersion offered to students in a real-life public health challenge, with dedicated support from clinician mentors, would not have been possible if the experience had been delivered face to face.

2.2. Success factors

Feedback and reflections from interviewees pointed to four factors that were crucial to the success of the VIC, as listed below.

The **first factor** was the 'virtual immersion' in the challenge context. Student participants were offered unique access to the national COVID-19 environment, from both clinical and public health perspectives, with exposure to the 'front line' of Singapore's response in a local hospital and migrant workers' dormitories. This immersion in real-world contexts, together with the targeted support offered by clinical mentors, was pivotal to the students' progression in this time-limited activity and supported the development of insightful and innovative solutions. Interview feedback made clear that this access to and mentorship from clinicians also underpinned high levels of student engagement and focus, despite many working with previously unknown team-mates in an online environment.

The **second factor** was the on-demand, flexible support offered. Participants spent the majority of the two-day challenge working in Zoom break-out rooms with their team. Given that more than half of participants had yet to start their formal studies at SUTD, a lack of clarity on both the design process and the VIC deliverables presented a real risk for teams in this time-limited activity. However, interview feedback suggested that the on-demand facilitation offered by the graduate mentors allowed teams to call for support as and when needed. Facilitators offered practical support and helped students develop the types of mindset and approach that might help them to tackle the challenge.

The **third factor** was the close working relationship between SUTD and CGH. The VIC built on an established working relationship between SUTD and CGH, which had already seen the development of a new undergraduate healthcare educational partnership. The trust built through this relationship, as well as a pre-existing understanding of constraints and opportunities offered by each partner, appears to have been pivotal to the rapid implementation of this activity and its ability to enrol so many clinical mentors.

The **fourth factor** was the levels of pre-planning put in place**.** The VIC was devised and designed in a very short time period; in the three weeks prior to its launch. Despite this rapid turnaround, considerable time and staff resources were invested in planning and preparation for the activity. For example, in addition to training of the graduate mentors, rehearsals were held with clinician mentors and activity judges to identify and resolve any technical issues and ensure that all contributors understood the challenge context, the scoring rubrics, and the structure of the two days. The organisers also prepared back-up versions of all presentations in case of network problems, and located organising committee members in different parts of Singapore to minimise the impact of any internet connectivity issues arising in particular geographical areas.

2.3. Challenges faced

Interviewee feedback pointed to two key challenges faced in the delivery of the activity. Strategies are in place to tackle these issues in any future deliveries of the activity. These changes are outlined below.

The **first challenge** was the lack of breaks in the two-day schedule. Although the activity scheduled two half-hour breaks for lunch each day, in reality, team-working and mentoring sessions expanded to fill the whole two days. With no formal schedule for mentors or event organisers to check in on teams, students were often left unsure when they were able to take breaks from their screens. As a result, most teams continued to be logged on throughout both days, without taking formal breaks, leaving many fatigued by the close of the activity. For future iterations of the activity, organisers plan to embed mechanisms by which teams are able to take structured breaks from working without penalty to their access to mentoring support.

The **second challenge** was the omission of hands-on, prototyping opportunities. Hands-on learning and prototyping are core features of the SUTD education, features which are highly valued by current and prospective students alike. It is therefore perhaps not surprising that participants pointed to the lack of a prototyping element as a weakness of the VIC. While embedding a hands-on element was not feasible for the 2020 activity, in the midst of the COVID-19 pandemic, plans are in place to support prototype development for future iterations of the activity.

2.4. Advantages of online delivery

Interviewee feedback suggested that the online format of the VIC offered important advantages to the organisation of the activity and to student learning, beyond what might have been possible if the activity took place face to face.

The key benefit was the ability to secure a group of 21 clinicians – each of whom was involved in the screening, prevention and treatment of COVID-19 in Singapore – to play an active role in this synchronous activity, through offering information, support and mentorship to the student participants. As many interviewees noted, it would not have been possible to secure the time of this group if they had been required to travel to the SUTD campus to make these contributions. With clinicians dialling in remotely from home, work or while commuting, the online nature of the activity facilitated such real-time connection.

Interviewees also pointed to a number of other benefits of the activity's online delivery. For example, the ways in which teams were able to connect with design mentors – through the messaging app Telegram – allowed them to benefit from targeted support as and when needed, with mentors able to join the team almost immediately upon a request for help. Some also noted that the online nature of the activity supported ongoing sharing of learning between teams, with students benefitting from accessing the questions posed by peer teams through the messaging app and learning from the responses given by mentors and organisers.

3. Activity details

3.1. Participants and project groups

Around half of the 58 participants were 'future' SUTD students, due to start their undergraduate studies in September 2020. Students were given the option to form their own teams. The remaining participants were allocated to teams based on a pre-activity survey of students' prior experience with the design process and their personality profile. It was a requirement that all teams contained at least one current student (who had therefore participated in SUTD's *Introduction to Design* course and had prior experience of undertaking design projects).

3.2. Structure of the two days

Structured around the '4D' (or 'Double Diamond'[1]) design process, the two-day activity is divided across the four stages of Discover, Define, Develop and Deliver:

1. Discover The opening session, on the **Saturday morning**, exposed students to the environment and challenges at the front line of Singapore's response to COVID-19, to set the stage for the VIC. Activities included: a panel from CGH to provide perspectives from the hospital and public health sector; videos highlighting particular challenges in the management of hospital wards and screening processes; an interactive virtual tour of the wards and migrant workers' dormitories. Students were also given a 40-minute 'crash course' in design methods and the ideation process, which was particularly targeted at the 'future' SUTD students who had not yet experienced the SUTD approach to design. At the end of this opening session, students were introduced to the 14 different 'case scenarios', each identifying a key challenge facing Singapore's pandemic response. Teams selected their preferred challenge (allocated on a first-come-first-served basis) and opened discussions on their problem statement and mission.

2. Define During the second session, on the **Saturday afternoon** students reframed their problem statement for their challenge, identified existing solutions and defined their team mission. On-demand facilitation and guidance was provided by graduate mentors. In addition, clinical mentors connected with teams to provide background information and answer any questions they had about their challenge context.

3. Develop In the third session, on the **Sunday morning**, teams used user personas and journey maps to explore the challenge from the end-user perspective, and developed a range of possible solutions. Teams undertook a 'mindmapping' process – based on user needs and concerns – to explore the feasibility, practicality and usability of each solution. Collaborative sketching and/or 3D modelling were also used to illustrate their ideas. Teams then selected and developed their preferred solution, which were further refined in discussion with their clinical mentors before their presentations.

4. Deliver In the final session, on the **Sunday afternoon**, teams developed and delivered a five-minute pitch of their challenge, design process and idea. The pitch was delivered to a

[1] The Double Diamond approach is outlined on the Design Council website: https://www.designcouncil.org.uk/news-opinion/what-framework-innovation-design-councils-evolved-double-diamond

panel of judges which included the then Chairman of the Medical Board of CGH, SUTD leadership, and the director of the SUTD Entrepreneurship Centre. As each team tackled a different case scenario, the final session exposed participating students to 14 different challenges and solutions across all three pandemic phases: pre-pandemic; ongoing pandemic; and post-pandemic. Similar to the opening 'Discover' session, these presentations were open to the wider SUTD and CGH communities.

DISCOVER	DEFINE	DEVELOP			DELIVER
Opportunities	Problem Definition	Ideation			Product/ Service/ System
Reframe the problem statement and mission	Identify improvements and opportunity gaps	Ideate potential solutions	Brainstorm user needs and concerns	Decide on a solution to focus on	Present idea solutions
Hierarchy of purpose	Desktop Research	User Personas & Journey Map	Mind map & C-Sketch	Real-Win-Worth It	Presentation
DAY 1		DAY 2			

3.3. The challenge brief

Teams were asked to select one 'case scenario' and associated problem statement from 14 options presented by CGH clinicians around the theme: "**Re-imagining healthcare in the time of COVID-19**". Case scenarios were allocated to teams on a first-come first-served basis, such that each challenge was being tackled by one team. The 14 case scenarios posed by the clinicians spanned the three key stages of a disaster response cycle:

Pre-pandemic	Five 'case scenarios' were set in the pre-pandemic stage, which focused on mitigation and preparedness. One sample case scenario and problem statement are given below: ***Case scenario:*** *International surveillance of emerging infectious diseases is an important component of the public health function. There is growing evidence that a new virus is showing regional spread in one part of the globe. The impact on Singapore needs further clarity.* ***Problem statement:*** *How might we use technology to monitor and assess the significance of potential infectious disease outbreaks in other countries?*
Ongoing pandemic	Five 'case scenarios' were set in the current pandemic stage, which focused on the response. One sample case scenario and problem statement are given below: ***Case scenario:*** *Many patients have presented to public hospitals with fever, coughing and acute respiratory distress. Their chest X-rays and CT scans show lung changes typical of COVID pneumonia. Within a few days, ICUs are caring for patients who are*

	deteriorating and require endotracheal intubation for mechanical ventilation. The surge in demand for ventilators may pose challenges to patient care. ***Problem statement:*** *How might we design a triaging tool to select which patients to intubate and ventilate, and which not to? How might we convince clinicians that the tool can make better 'life and death' decisions than them?*
Post-pandemic	Four 'case scenarios' were set in the post-pandemic stage, which focused on the recovery and the 'new normal'. One sample case scenario and problem statement are given below: ***Case scenario:*** *The development of vaccines seems to be a constant catch-up game where respiratory viruses e.g. influenza virus, coronavirus, are concerned. This is mostly due to the rapid mutation rate of such viruses.* ***Problem statement:*** *How might we pre-emptively design a 'perfect' vaccine even before a disease outbreak begins, while ensuring that the vaccine is affordable by most countries? (After all, until all of us are safe, none of us are safe).*

3.4. Deliverables

The final deliverable – presented by student teams at the close of the two days – was a **five-minute online pitch** which outlined the team's case scenario, their design process, their idea/solution, and the team's future plans. Four judging criteria were adopted for these presentations:

- **Solution fit:** *does the proposed solution address the problem and user needs effectively?*
- **Innovation:** *does the solution present a creative and original approach to solving the problem, that is also feasible and implementable?*
- **Design-thinking:** *how well has the team used the design-thinking framework (discover, define, develop, deliver) to inform their solution?*
- **Presentation:** *how well is the team able to articulate their proposal and engage the audience?*

In addition, teams were asked to submit online a **short report**, which brought together the five interim deliverables that teams submitted over the course of the two days:

- refined problem statement;
- team mission;
- existing solutions to the problem statement;
- user personas;
- user journey map.

The VIC was extra-curricular and non-credit-bearing for the students' undergraduate studies.

3.5. Learning outcomes

The four primary learning outcomes for the VIC, as specified by SUTD, are provided below:

1. *to engage frontline CGH clinician leaders to share their experience and perspectives on the COVID-19 crisis and its associated healthcare challenges;*
2. *to promote SUTD's culture of design and co-creation to current and future students;*
3. *to introduce student participants to useful design methodology and tools;*
4. *to provide an opportunity for collaborative team-based learning and networking.*

3.6. The teaching team

The team engaged in the development and delivery of the VIC included:

- two faculty leads from SUTD and two clinical leads from CGH;
- 21 clinical mentors from the COVID-19 response team at CGH;
- five graduate mentors from SUTD, including one coordinator;
- webinar speakers, judging panel, and organising committee, including leaders, innovators and clinicians from both SUTD and CGH.

Graduate mentors had all participated in SUTD's *Innovation By Design* courses, and had all attended a training session prior to the VIC. The two major areas of focus for the graduate mentors when engaging with the teams were:

- **students' mindset:** ensuring that teams understand what is expected of them throughout the VIC, and (in particular) that they are punctual and play an active and positive role in their team's activities;
- **team progress:** ensuring that teams are clear about the goals and deliverables for the VIC and keep on track throughout the two days.

Graduate mentors were provided with a written briefing – the 'Facilitator's Toolbox' – which outlined the key priorities for facilitation, the detailed schedule for the two days, and the key team deliverables.

3.7. Technology used

The following applications and technologies were used in the delivery of the four key phases of the VIC:

1. Discover	• Zoom was used for the webinar sessions, with student participants hidden from view except during the Q&A sessions, where they were able to ask questions using the 'chat' function. • 360º immersive cameras were used to allow students to explore the environment at the CGH emergency room and at migrant workers' dormitories.

2. Define & **3. Develop**	• Zoom breakout rooms were provided for each student team. • All students were invited to join a private channel of the messaging platform Telegram, which allowed teams to ask questions or seek help from mentors or activity organisers in real time. Telegram was also used to broadcast instant messaging reminders to the teams about various project deadlines. • Google Drive Folders contained a design toolkit for student teams, with information on the activity schedule, deadlines and templates for each of the VIC deliverables.
4. Deliver	• Zoom webinars were used for the closing presentations given by each team. • Google Drive Folders were used for the submission of final reports from each team.

Source of evidence

The case study for SUTD (including Part A, this review of the VIC, and Part B, the review of the 'institutional context') drew upon one-to-one interviews with 10 individuals: the SUTD Associate Provost; the SUTD Director of Undergraduate Studies; the two co-faculty leads of the Virtual Ideation Challenge from SUTD; two clinician mentors from Changi General Hospital (one of whom was the activity coordinator from Changi General Hospital); the coordinator of the graduate mentors for the VIC; and three SUTD undergraduates.

Further information about the methodology for development of CEEDA case studies is given at the project website[2].

[2] CEEDA case study structure and approach: https://www.ceeda.org/about#case-studies

SUTD, Singapore

Case Study Part B – Institutional context

Undergraduate engineering student intake (1st year cohort 2020/21):	**≈ 450**
Number of engineering faculty:	**≈ 120**
Duration of undergraduate engineering degree (to BEng):	**3.5 years**

1. Defining features of SUTD's engineering education

Established in 2009 in collaboration with MIT, SUTD is a specialist design and technology university, catering to a select intake of around 500 undergraduates per year. A defining feature of the university is its multidisciplinary, active and student-centred educational approach, which is underpinned by team-based problem solving and collaboration. All undergraduates are based on campus to support access to dedicated team working and prototyping spaces, and to advance peer-to-peer learning.

Because SUTD takes a hands-on approach to education, remote learning is not a feature of its current and future educational vision. However, educational technology and the development of cyber-physical systems – as tools to allow students to explore new ideas, deepen their learning and offer individualised learning while on campus – play a major role in the university's educational vision for the future. Drawing on strategic external partnerships in educational technology, SUTD is investing significantly in Artificial Intelligence (AI), data analytics, robotics and AR/VR. Early developments already rolled out in the curriculum include the use of AI[1] and AR/VR[2] in the teaching of mathematics and AR/VR Architecture studio modules[3]. New initiatives in the pipeline to realise the university's vision of cyber-physical systems include the development of: 3D/AR whiteboards (to allow, for example, students to explore, annotate and present 3D models) and a virtual campus (to support virtual tours of SUTD and to showcase students' 3D projects). SUTD is also looking at ways to leverage emerging technologies to develop new learner analytic and 'anti cheating' systems, for application to both online and offline learning. The university points to the willingness of its faculty to embrace a non-traditional and constantly evolving curriculum as a major strength in its capacity to advance innovations in educational technology.

[1] Example of the use of AI at SUTD: https://player.vimeo.com/video/444750185?dnt=1&app_id=122963

[2] Example of the use of AR/VR at SUTD: https://ieeexplore.ieee.org/document/9045957

[3] The use of AR/VR in SUTD's Architecture studio module 20.317: https://asd.sutd.edu.sg/programme/bachelor-of-science-architecture-and-sustainable-design/courses/20317-augmented-design

2. SUTD's experience of emergency teaching in engineering

2.1. Emergency teaching restrictions

During the two-month 'circuit breaker' period of total lockdown across Singapore during April and May 2020, SUTD's programmes moved entirely online.

After more than a month (from April 8th to May 17th 2020) operating in a fully online mode, SUTD moved to a blended model between May 18th and Sep 13th 2020. During this period, many courses were still delivered online, but a limited number of labs, architecture-style studios, hands-on projects and examinations were able to go ahead face-to-face, albeit under stringent social distancing restrictions.

From September 14th 2020, all first year classes were delivered face-to-face on campus provided that the class size was under 50; first year students in larger class sizes and those in other year groups continued to operate under blended learning conditions.

2.2. Managing the transition to emergency teaching

In its immediate response to the COVID-19 restrictions and its shift to online learning in March 2020, the university shipped IT devices to faculty (such as Wacom tablets, iPad Pros, microphones, webcams) to support their capacity to develop and deliver online courses from home. Faculty were also offered training in the use of some of the key applications adopted for this online learning environment, including MS Teams, Hiverlab[4] (for AR/VR activities) and ClassPoint[5] (to integrate student feedback and interactivity into presentations). SUTD currently supports a variety of platforms for synchronous and asynchronous teaching, including:

- **synchronous:** video meeting and collaboration platforms (e.g. Zoom, MS Teams, Blackboard Collaborate); platforms to advance student participation (ClassPoint and Slido);
- **asynchronous:** screen recording (PowerPoint) and content creation (eDimension[6]).

Initial barriers to SUTD's emergency online learning (as reported by students) typically related to internet connectivity and home environments that were unconducive to learning. Despite these early challenges, faculty reported high levels of student engagement in online team-based activities, which was largely attributed to the opportunities for peer-to-peer connection and interaction that these experiences provided.

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[4] Hiverlab: https://www.hiverlab.com

[5] ClassPoint: https://www.classpoint.io

[6] eDimension: https://www.sutd.edu.sg/educational-technology/Learning-Solutions-and-Applications/eDimension

2.3. Addressing the challenges of emergency teaching

The major challenge faced by SUTD has been in the remote delivery of its hands-on and collaborative project-based activities. This has related particularly to guiding students through the collaborative design process, the development and construction of physical prototypes, and the showcasing of project outputs. Since March 2020, the university has developed and rolled out a number of new online solutions that target these particular areas. Examples include team-based games (such as multi-player logistic simulation games hosted on a remote server[7] and gamified virtual labs to teach cell biology) and e-exhibitions (such as virtual showcases of students' product design solutions, including for Capstone projects[8]). Where on-campus hands-on activities have been possible, smart cameras with facial recognition have been adopted to limit the number of students using prototyping facilities at any given time, with robotics supporting real-time monitoring of safe distancing among the users.

3. Impact of emergency teaching on SUTD's educational approach

While SUTD's fundamental emphasis on hands-on collaborative problem-solving and innovation remains unchanged, the COVID-19 restrictions have accelerated the university's plans for the development of cyber-physical systems to support its on-campus learning. In particular, the period of emergency teaching has fast-tracked SUTD's work to develop digital twins and AR/VR content as substitutes for physical systems and prototypes. These advances will also be used to underpin new and immersive modes of collaboration with overseas students and global partners. A second priority is the development of personalised approaches to teaching and learning, be that online (through new advances in learner analytics) or in the classroom (through sensor technologies tracking student behaviour that will allow the university to optimise the physical learning environment). SUTD's experiences during this period have also underlined the distinctive culture and educational approach of the university and its student community, which is reflected in the ways such technologies are accessed and used. This has galvanised SUTD's ambition to pursue bespoke, rather than off-the-shelf, educational technology solutions in the future.

[7] ESD Games, SUTD: https://esd.sutd.edu.sg/esd-games/

[8] Virtual Capstone Design Showcase, SUTD: https://capstone.sutd.edu.sg

Source of evidence

The case study for SUTD (including Part A, the review of the Virtual Ideation Challenge, and Part B, this review of the 'institutional context') drew upon one-to-one interviews with 10 individuals: the SUTD Associate Provost; the SUTD Director of Undergraduate Studies; the two co-faculty leads of the Virtual Ideation Challenge from SUTD; two clinician mentors from Changi General Hospital (one of whom was the activity coordinator from Changi General Hospital); the coordinator of the graduate mentors for the VIC; and three SUTD undergraduates.

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[9] CEEDA case study structure and approach: https://www.ceeda.org/about#case-studies

PUC, Chile

Case Study Part A – Best Practice Activity

Engineering Challenges

Student cohort:	**830**
Location:	**100% online**
Duration:	**1 semester (≈15 weeks)**
Date delivered:	**March – June 2020**
Activity type:	**Core 1st year course**
New/existing:	**Existing activity**
Hands-on element:	**At home prototyping**
Cross time-zones:	**No**

Distinctive feature of case study

Undergraduate teaching assistants co-creating the course's transition online

Abstract

Activity overview

Engineering Challenges is a first-year design course at the Pontifical Catholic University of Chile (PUC) that challenges multidisciplinary teams of engineering students to develop technology-based solutions to major societal challenges facing Chile.

Independent review

Engineering Challenges caters to a large student cohort and combines a wide range of pedagogies and learning outcomes. Moving the course online was therefore a major undertaking. The success of this online pivot was underpinned by the inclusive and flexible approach taken to co-design by the teaching team, in which undergraduate teaching assistants were empowered to develop and roll out incremental improvements to the course in real time, in response to the students' experiences and feedback.

Activity details

Engineering Challenges is a semester-long course – bringing together all incoming engineering students – that moved online for 2020. The course is structured around the user-centred design process with a particular focus on building empathy with a team's chosen user group. The course also introduces students to the broad principles and applications of engineering, and supports the development of their prototyping, modelling and presentation skills.

1. Activity overview

Engineering Challenges is a 'cornerstone' course that provides incoming students – from across the school – with both an introduction to the field of engineering and a framework for their learning over the rest of the five-and-a-half-year undergraduate programme. While the course brings together a significant number of components, pedagogies and learning outcomes, its backbone is a user-centred design project that focuses, each year, on a different societal challenge facing the country. In 2020, the theme for the design project was 'Lockdown'. Over 800 newly-enrolled engineering students – none of whom had met in person before starting – were tasked with developing a technology-based solution that addressed challenges facing the Chilean population living under tight COVID-19 restrictions.

To support the development of their team-based project, the course takes a highly structured approach to guiding students through the user-centred design process, scaffolding their progress and learning throughout the semester. This training and development includes scheduled classes in topics such as data analysis and materials selection, workshops to develop modelling and prototyping skills, and sessions dedicated to peer learning and self-reflection. Building empathy and understanding with each team's chosen user group is also a prominent theme; teams must work independently to reach outside their own communities to engage with and listen to members of their user group, as well as work with them to test ideas and prototypes. The course learning outcomes also focus on students' mindsets and skills – including their confidence, collaboration, engagement, ethical decision-making, problem-solving, creativity, prototyping – within a team-based environment.

The introduction of COVID-19 restrictions in Chile – which took all teaching at the university online with immediate effect in March 2020 – coincided with the scheduled start of both the academic year and the Engineering Challenges course. Due to the size and complexity of Engineering Challenges, a number of different approaches were employed to pivot the course online. One major adaptation was to the requirement for teams to produce functional prototypes of their solutions: in the 2020 course, teams were asked instead to develop and test their prototype using 3D modelling, as well as create a 'mockup' of their design using materials found at home.

2. Independent review

2.1. Distinctive features

Before the 2020 online pivot, Engineering Challenges stood apart from peer engineering project-based courses in two key respects. Firstly, the course supports a deep societal connection, with a new theme each year that responds directly to a key challenge facing Chilean society, such as the need for low-cost emergency housing following devastating fires in the country. Secondly, the course required students to travel off-campus to connect independently and directly with their chosen user groups; in the example above, students connected with groups such as firefighters and families displaced by the fires.

While these features set Engineering Challenges apart during its pre-COVID, face-to-face delivery, interview feedback pointed to one overriding feature that distinguished the course's transition to online delivery: **co-creation by undergraduate teaching assistants (UGTAs)**. UGTAs have long played an important role in the course's design and delivery, including offering mentorship to the teams and delivering workshops to develop students' prototyping, testing and presentation skills. Interview feedback suggested that the engagement of the UGTAs was also integral to the success of the online pivot of Engineering Challenges and its ability to respond quickly and effectively to student feedback.

In March 2020, the teaching team had less than two weeks' notice to redesign Engineering Challenges for online delivery. The UGTAs' engagement both helped to shape the immediate approach to this online pivot, and to ensure the iterative improvements and changes made to the course throughout the semester. So, for example, prior to the course launch, UGTAs proposed that they deliver a second week of skill-development workshops during the course, to consolidate and apply students' learning. Drawing on their own experience as undergraduates adapting to an online learning environment, the team of 55 UGTAs were also well-placed to listen to and empathise with the challenges and opportunities faced by students during the delivery of the Engineering Challenges course. Acting as a bridge between undergraduate participants and the course teaching team, these issues were quickly identified and acted upon through weekly meetings between the lead UGTA and course director. While many of the ongoing, incremental changes made were minor, they were reported to have played a major role in building student motivation and engagement. Changes informed by UGTA feedback included: (i) when and how course materials and feedback were delivered, such that students were better able to plan and structure their time; and (ii) the online messaging tools used for communication between teams and mentors, which facilitated quicker responses that could also be accessed by students across the cohort.

2.2. Success factors

In addition to the co-creation with UGTAs (as outlined in the 'Distinctive features' section above), interviewee feedback pointed to two further inter-related factors that underpinned the success of the online pivot of Engineering Challenges.

The **first factor** was high levels of student engagement. Interview feedback suggested that the levels of student engagement in the online iteration of Engineering Challenges were consistently higher than those apparent in previous years. Described by many as a "*love it or hate it course*", Engineering Challenges had long divided opinion amongst participating students. Some viewed the course as excessively time-consuming for its 10-credit load, squeezing the time they could otherwise devote to the fundamental engineering science courses that populate the rest of the first-year curriculum. Others clearly drew considerable inspiration and engagement from tackling authentic societal challenges in a competitive team-based environment. These differences in student opinion were still apparent amongst participants in the 2020 online iteration of Engineering Challenges: however, feedback from course leaders and UGTAs pointed to a marked reduction in student dissatisfaction as compared to previous years. Most attributed this to two factors. The first was the opportunity for meaningful interaction and connectivity that the course offered the newly enrolled student cohort, at a time when they were isolated within their homes and studying a curriculum that was otherwise largely delivered in a lecture format. The second factor was that the online delivery appeared to significantly reduce the time burden imposed by Engineering Challenges: the use of Zoom for classes, team interactions and for students' interaction with user groups eliminated the need for students to travel to and from campus across the city which, for many, could consume many hours of their week.

The **second factor** was flexibility in the course design. The structure, focus and design of Engineering Challenges have been under continuous redesign and development since its establishment in 2002, as informed by student feedback and review by the teaching team. Interview feedback suggested that this flexibility of the teaching team – not being wedded to a fixed idea of what the course must look like – played a crucial role in its 2020 online pivot. So, for example, when some elements of the course proved problematic to deliver in a remote online setting (such as students' engagement with external user groups or the development of functional prototypes), the teaching team was able to place emphasis on other course elements that were supported by the online delivery (such as students' presentation skills and 3D modelling of prototypes). The course director has played a pivotal role in establishing this flexible and responsive approach: in canvassing feedback, reviewing the issues emerging and driving iterative ongoing improvements to the course, both prior to and during the period of 'emergency teaching'.

2.3. Challenges faced

Engineering Challenges brings together a range of components, pedagogies, and learning outcomes, all delivered to a large and diverse student cohort. As such, the online pivot for the course was a major undertaking. When discussing the challenges associated with the online delivery of the course, interviewee feedback fell into two distinct categories – one focused on the logistics of course delivery and one focused on particular course elements – as outlined below.

Course leaders, school leaders and UGTAs spoke about difficulties associated with the logistics of online course delivery at a time of great uncertainty. These included:

- the instability of faculty and students' internet connections, which presented a particular challenge as the vast majority of the course was delivered synchronously;
- the inability of the teaching team to provide students with a confirmed timetable and set of deliverables for the course, due to changes and uncertainty in the semester schedule;
- the lack of insight into the engagement levels of many student participants, as a high proportion kept webcams turned off during section-wide activities;

- the difficulty of ensuring that students across the 10 discrete course sections each experienced the same quality of learning when teaching teams were unable to interact face-to-face and share their approaches.

Interviewees also pointed to particular course elements of Engineering Challenges that were especially problematic to deliver remotely and online. Three were repeatedly highlighted.

The **first** was supporting informal connectivity across and between teams. Engineering Challenges is one of five courses that students study on entry to the engineering school, and is the only one that relates specifically to engineering or that integrates team- and peer-based learning. As such, it offers the major curricular mechanism for engineering students to connect and build friendships and networks. While students were able to work and interact within their teams of seven in the 2020 course, interviewees pointed to particular difficulties faced in allowing students to 'mingle' informally and make new connections across different teams. This happened organically in previous years by virtue of students sharing the same physical spaces. As the 2020 course progressed, the teaching team therefore created new activities to support student interaction outside their own teams. For example, students were randomly paired to practice their interviewing technique with another student from the course. In addition, teams were divided in half, and half-teams were randomly paired together to listen to and provide feedback on early iterations of each team's challenge solution and final 'pitch'.

The **second** was establishing meaningful engagements with user groups. A fundamental characteristic of Engineering Challenges is the requirement for teams to identify and build empathy with their chosen user group. Prior to 2020, teams were asked to travel off campus to meet with, and interview, user group members at specific points in the design process, to better understand their needs, experiences and perspectives. These interactions were designed to challenge assumptions and preconceptions that students might have held about users from demographic groups different to their own; it had been a clear stipulation of the course that these users should not have been previously known or connected to any members of the team. Without the ability to travel outside their homes in the 2020 online course delivery, teams struggled to identify and broker such new external connections. The teaching team therefore amended its guidance to allow teams to draw upon the network of the school's student and alumni networks to forge virtual connections with user groups, and also to allow them to speak with individuals with insight into the user group rather than the group themselves (so, for example, speaking to school teachers rather than children).

The **third** was creating an interactive and engaging closing exhibition. Engineering Challenges closes with what is described as a 'technological fair': a major exhibition, open to the public, where students showcase their ideas and interact with visitors and judges from industry and the regional community. UGTAs, in particular, spoke about the importance of this exhibition as a culmination to the course during previous years, and the pride and excitement of students as they exhibited their projects. In the words of one UGTA, "*it is a formal thing, we put on our suits and everyone comes to see what we have done. It is a closure for what we have achieved*". While the technological exhibition was delivered at the close of the 2020 course, many interviewees noted that its online delivery (using Zoom) did not offer students an equivalent to the face-to-face experience in terms of the "*atmosphere of excitement*" or the ability to network with individuals from across and beyond the university.

2.4. Advantages of online delivery

Despite the challenges faced, teaching team members pointed to three respects in which the online delivery of the 2020 Engineering Challenges offered advantages over the face-to-face approach used in previous years.

The **first advantage** was the flipped classroom approach. Engineering Challenges dedicates three hour-long 'classes' per week to introduce students to fundamental engineering concepts and the key stages of the user-centred design process. In previous years, this class time was devoted to a mixture of lectures and peer-learning activities in topics such as data analysis, estimation, and materials selection. In the 2020 course delivery, all theoretical content was delivered in the form of short videos made available in advance, with the synchronous 'class' time dedicated wholly to discussion and activities. Teaching team members consistently noted the advantages of this approach, which allowed much more flexibility during class time for students to apply their learning to their team projects.

The **second advantage** was the greater focus on modelling and presentation of ideas. The 2020 course delivery removed the workshop training component as well as the requirement for teams to build a functional prototype. Instead, teams were asked to develop 3D models as well as create at-home mockups of their solutions. Despite the loss of important hands-on learning components, teaching teams pointed to the benefits that teams derived from having additional time to devote to iterating their ideas and presenting their final solutions. In previous years, the prototype build was often time-consuming and a task that teams therefore started at a relatively early stage in their solution development. Teaching team members noted that the development of online 3D models allowed teams to dedicate more time to iteration and testing of their ideas, which resulted in more appropriate and well-considered solutions. The quality of final presentations was also noted to have improved, with teams dedicating more time to developing their pitching and design skills.

The **third advantage** was the greater efficiency in team working and evidence gathering. Students and teaching team members noted that the use of videoconferencing and other online interaction tools adopted for the 2020 course played an important role in increasing the efficiency of many team tasks and activities. Most prominent was the reduction in time spent in travelling to and from the PUC campus, which is based in a suburb of Santiago, to connect face-to-face with other team members or user groups. Messaging platforms, such as Discord, were seen to improve communication between groups and with UGTAs, providing rapid answers to questions that could be shared across the student cohort. Other technologies were employed within teams to improve decision making, such as a system by which team members could vote anonymously for their preferred idea from the selection of those proposed during the ideation process.

Plans are in place to incorporate each of the above components into Engineering Challenges after the COVID-19 restrictions are lifted. The teaching team is also considering taking some of these ideas further in next year's course. One example is to connect teams remotely with the Challenge 'judges' – the group of 80 engineers, designer and experts in the Challenge topic who assess teams' solution at the end of the semester – at an earlier stage in the course, such that teams can benefit from their feedback during the design process.

3. Activity details

3.1. Participants and project groups

All incoming students to PUC Engineering take the Engineering Challenges; in 2020 the cohort size was 830. This full-year cohort is randomly divided into 10 sections of 80–85 students, with each section overseen by one engineering faculty member. The sections are divided into 12 teams, each of around seven students. The composition of the teams is based on an algorithm that ensures at least two women in each team, with members taken from a range of backgrounds, engineering disciplines, modes of entry to the university and geographic locations pre-university entry.

Students enter the course from high school, with almost no background in either engineering or design. The cohort participating in the online version of Engineering Challenges in March 2020 were all new to the university and very few had connected in person prior to the course.

3.2. Structure of the course

Engineering Challenges[1] is a course delivered in the first semester to all first-year students entering the engineering school. As a 10-credit course from a total 50-credit load in the first semester, students are expected to dedicate 10 hours per week to Engineering Challenges, which includes three hours of scheduled 'class time' with most of the remaining time dedicated to team-based project work. It should be noted that the course usually runs for 15 weeks, but this was reduced to 12 weeks for 2020 to accommodate the rapid shift online as well as the introduction of an additional 'recess week'.

Outlined below are the major components included in the 2020 online delivery of the course.

[1] Engineering Challenges online course information: http://ing1004.ing.uc.cl.

Kick-off session	In the opening week, video footage and guest speakers were used to introduce the challenge context to student participants. A video was also shown featuring members of the previous year's winning team, who offered reflections and advice for the new student cohort.
Team projects	The spine of the course was the team-based project, which was structured around the user-centred design process. The four main phases of the project development were: • **Context assessment:** teams identified a user group within the challenge context and developed empathy with and understanding of the group's experiences, needs and aspirations through conducting at least 30 interviews. Teams also selected their chosen problem and identified a range of existing solutions. • **Design opportunity:** teams selected one design opportunity, identified a range of existing solutions and ideated three possible novel solutions. • **Idea development:** teams developed, modelled and created one mockup prototype of their chosen idea. • **Analysis and testing:** teams tested their solution (both using 3D modelling as well as gathering feedback on the concept from user and expert groups), and prepared their five-minute 'pitch' for the closing exhibition. At the close of each phase, teams presented their progress/ideas to their 'section' of the course, which comprised 12 teams.
Structured 'classes' and development	Throughout the semester, three hour-long classes per week were used to deliver theory and build skill development (in topics such as mathematical modelling and interview techniques) to support and inform students' progress at each stage of the design process. In the 2020 course, these classes took a 'flipped classroom' approach, with the 'theory' delivered in advance in the form of short videos, and synchronous class time dedicated to discussion around the topics or application of the ideas within teams.
One-week workshops	During two separate weeks of the course, UGTAs delivered workshops to build the skills students needed to design, research, test, validate and present their solution online. Each team member was expected to attend a different workshop and relay their learning back to the rest of the team. While pre-2020 workshops covered skills such as CNC machining and laser cutting, the 2020 workshops focused on skills that students could develop and apply at home. Five core workshops were offered to students in all sections (Arduino, Illustrator, physical 'at home' prototyping, digital prototyping, and 3D modelling). Additional workshops were also designed to respond to the particular projects under development in each section and the particular skills that members would need to prototype and present them. The second week of workshops was introduced for the 2020 course, to provide additional and dedicated support for students to apply these particular skills to their team's project.
Technology exhibition	The culmination of the semester-long course was a closing exhibition, where teams pitched their ideas to a judging panel of engineers, designers and subject-matter experts. The exhibition was open to all members of the academic and regional communities.

3.3. The challenge brief

The challenge theme for the course changes each year, and is a closely-guarded secret before it is announced to the full student community during the first week of the semester. The challenge theme for Engineering Challenges 2020 was 'Lockdown': the confinement of the national population during the COVID-19 pandemic. Teams were able to consider this theme from the individual or systems perspective. Within this broad theme, the solutions[2] developed by teams addressed a wide range of problems, including how garbage build-up can be reduced in tenement buildings, how to provide exercise for dogs who were unable to be walked outside, and how to offer daily structure for autistic children who were dislocated from familiar routines outside of the home.

3.4. Deliverables and assessment

Similar to the previous face-to-face delivery of Engineering Challenges, the 2020 course incorporated deliverables both for each team and for each individual student. These team and individual deliverables are outlined below.

Team deliverables: teams were asked to deliver presentations at the conclusion of each of the four major phases of the course. Each 'section' of 80–85 students came together for these presentations, which each took place over one week. Structured around the user-centred design process, the four presentations focused on:

1. *context assessment:* identification of, and data gathered from, the team's chosen user group;
2. *design opportunity:* presentation of design requirements and three potential solutions;
3. *development of idea:* development and prototyping of the team's chosen idea;
4. *analysis and testing:* presentation of the team's chosen solution, including background research.

The final presentations were delivered via Zoom at an online 'technological fair' to two panels of judges, each comprising one engineer, one designer and one expert relevant to the team's solution. In this final five-minute 'pitch', teams were required to bring together key elements of their previous three presentations. For each of these four presentations, students provided peer-assessment on the contribution of their team-mates to the progress and working environment of the group.

Top-rated teams from each section were taken forward to a competition final at the close of the fair.

Individual deliverables: students were asked to submit ongoing assignments related to the weekly 'classes', which were typically evaluated by peers or UGTAs. In the pre-2020 iteration of Engineering Challenges, students also took a mid-term test and a final exam that explored their individual contribution to the group project. Both of these assessments were removed for the 2020 online delivery of the course. Feedback from teaching team members suggests that these components will

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[2] The deliverables produced by each team in the 2020 Engineering Challenges are available online: http://ing1004.ing.uc.cl/?page_id=2719

not be reintroduced into the course in the future, as their removal appeared to have limited impact on student learning and progress.

3.5. The teaching team

The teaching team supporting Engineering Challenges is outlined below:

- **10 engineering faculty members**, including one course director. Each faculty member oversaw one section of 85 students, delivered the weekly classes to this group (to a common template, consistent across all sections) and acted as a mentor to students teams (offering weekly technical support and feedback). The selection of faculty members changes each year depending on the blend of expertise that students will need to draw upon to tackle that year's challenge. The course director coodinated all participating faculty and UGTAs, who were taken from across and beyond PUC Engineering.
- **55 UGTAs**, including one lead UGTA. One team of five UGTAs was assigned to each section of 80–85 students, of which four were senior engineering undergraduates (who had themselves participated in Engineering Challenges during their first year of study) and one was a senior design undergraduate. UGTAs designed and delivered the workshops (which sought to build students' prototyping, modelling and presentation skills) and provided mentorship and advice directly to teams in their section. The lead UGTA's role was to gather feedback and suggestions from UGTAs across all sections, and to liaise with the course director.
- **80 judges**, working in groups of three: one engineer, one designer and one expert in the challenge context. The 'expert' judges were selected after the second team presentations – where the teams' ideas are showcased – to ensure that judges' background and experience were aligned with the types of problems and projects that teams were working on. For example, for the 2020 course, a significant number of teams focused on health (maintaining mental and physical health while under confinement) and sports (undertaking physical training while under confinement), so the expert judges selected included psychologists, clinicians, personal trainers and sports scientists.

Although not part of the teaching team, an undergraduate mentor is also assigned to each team of seven students on the Engineering Challenges course, to support their social development and integration into the engineering school throughout their first academic year of study.

3.6. Technology used

The following technology was used to support the online delivery of Engineering Challenges:

- Canvas was used to establish the learning map for the course, and provide students with all major materials such as readings, tasks, videos and content. Within Canvas, SpeedGrader was used to provide student feedback;

- Zoom and Google Meet were used to host all classes, team-working sessions, workshops and mentorship sessions;
- other platforms and chat functions were used by teams and UGTAs to share ideas, ask questions and interact, including Discord and Milanote.

Source of evidence

The case study for PUC (including Part A, this review of the *Engineering Challenges* course, and Part B, the review of the 'institutional context') drew upon one-to-one interviews with 12 individuals: PUC Engineering Dean; the PUC Engineering Director of Engineering Education; two leaders from *Engineering Challenges*; and eight PUC Engineering undergraduates (which included four UGTAs).

Further information about the methodology for development of CEEDA case studies is given at the project website[3].

[3] CEEDA case study structure and approach: https://www.ceeda.org/about#case-studies

PUC, Chile

Case Study Part B – Institutional context

Undergraduate engineering student intake (1st year cohort 2020/21):	**≈ 800**
Number of engineering faculty:	**≈ 170**
Duration of Bachelor of Science in Engineering:	**4 years**
Duration of professional engineering degree:	**5.5 years**

1. Defining features of PUC's engineering education

Like engineering schools across Chile, the Pontifical University of Chile's Engineering school (PUC Engineering) has historically delivered long (seven-year) undergraduate engineering programmes that were dedicated almost exclusively to mathematical and scientific fundamentals. The past decade, however, has seen a radical shift in the school's educational approach.

A shorter five-and-a-half-year undergraduate curriculum has been developed. While academic rigour remains at its core, three major new themes have emerged. Firstly, there is a stronger focus on interdisciplinary learning, with the introduction of new interdisciplinary programmes, activities and majors in areas such as sustainability and AI. Secondly, there is a greater emphasis on what is termed 'care', built both within the student and faculty communities (via a suite of support and mentorship programmes) and through connectivity with the regional and national community (with many curricular and non-curricular activities linked to external communities to address challenges and innovations in Chilean society and industry). Thirdly, greater prominence is given to design, entrepreneurship and innovation, whose prominence has grown significantly in the past five years. For example, the school has established a suite of opportunities to develop students' capabilities in technology-based entrepreneurship both within and outside the curriculum, including a 'sister' course to Engineering Challenges in the third year of study, where multidisciplinary student teams from across the engineering school work with regional entrepreneurs to develop and launch technology-based start-ups.

Educational technology has not played a prominent role within the PUC Engineering undergraduate curriculum. However, since 2015, the school has offered subsidies for faculty to create Spanish-language massive open online courses (MOOCs) across a range of topics to support engineering learning across Latin America. Since the transition to 'emergency' online learning in November 2019, the school's priorities for MOOCs' development have shifted: funding is now directed at MOOCs and associated online material that can be utilised within the PUC Engineering undergraduate programmes.

2. PUC's experience of emergency teaching in engineering

2.1. Emergency teaching restrictions

Due to social unrest across the country, the university first pivoted online in November 2019. Shortly after these emergency teaching measures were eased, they were reinstated due to the COVID-19 restrictions from mid-March 2020. The imposition of COVID-19 restrictions coincided with the start of the academic year and the start of the Engineering Challenges course, which, like all other courses in PUC Engineering, was taught 100% online.

2.2. Managing the transition to emergency teaching

The school took a decentralised approach to the online pivot. Faculty and teaching teams were asked to develop an online/remote version of their courses in whatever way worked best for their subject, students and areas of expertise. The only stipulation set by the Dean was that the approach must not disadvantage any student group, particularly those without access to fast/reliable internet or other equipment. So, for example, the Electrical Engineering department posted circuit components to their students, but did not penalise those unwilling to use the kit due to concerns of infection risk. Some interviewees noted that the online pivot at PUC Engineering benefitted from the MOOCs that many of the school's faculty had previously prepared; although never intended for delivery to undergraduates in the school, much of this material could be easily adapted to curricular courses and activities.

Interview feedback pointed to a number of benefits to student learning of this online pivot. Levels of student engagement with the online courses and materials were reported to be higher than pre-2020, with many students reviewing online materials multiple times in advance of synchronous classes. A "*closer relationship between professors and students*" was also reported, with a wider range of students willing to ask questions and post ideas through anonymous 'chat' functions than would have been willing to do so in person within a lecture theatre.

2.3. Addressing the challenges of emergency teaching

Interview feedback pointed to two major challenges faced by the school in its online pivot.

The **first challenge** was in student evaluation: the practicalities of administering mid- and end-of-semester synchronous tests and examinations, particularly where many students experienced intermittent or slow internet access. In response, the school moved away from large-scale exams at the mid-point and end of semester and instead instigated continuous assessments through, for example, weekly testing of students.

The **second challenge** was around students' mental health: both their exhaustion from dedicating long days working onscreen and their anxiety in coping with the uncertainty and impact of both the national social unrest and the COVID-19 pandemic. The Dean of the school instituted weekly meetings – open to the full undergraduate community – to allow students to raise and discuss the problems they were facing. Mid-semester student surveys of a number of courses, including Engineering Challenges, captured feedback on students' wellbeing and ability to work. As a result of the feedback received, a series of changes and adjustments were made to alleviate these difficulties. These included the introduction of a 'recess week' in the middle of the fall 2020 semester, where no additional work was set, and the appointment of additional psychologists to the school to offer students one-to-one mental health support.

3. Impact of emergency teaching on PUC's educational approach

The school's experience during its two periods of emergency online teaching – due to the social unrest in late 2019 and early 2020, as well as due to COVID-19 – is likely to have a considerable impact on its educational approach once face-to-face learning again becomes possible. As outlined below, four sets of changes are currently under discussion:

- **pedagogical approach.** Following the lifting of the COVID-19 restrictions, it is envisioned that many of the online delivery modes and associated pedagogical approaches will be maintained. For example, many courses will retain a flipped classroom approach, where online material will be delivered in advance in the form of short videos, and synchronous in-class time is dedicated to group-based or peer-to-peer learning. Courses involving hands-on learning will also retain a strong emphasis on 3D modelling and testing, as mechanisms to allow students to refine and iterate ideas further before embarking on the physical production of a functional prototype. In addition, much greater use will be made of videoconferencing when asking students to connect and interact with external stakeholders.
- **connectivity with society.** The school is looking at ways in which it can position itself even more explicitly – in both its research and educational activities – as an engine for positive societal and economic change in Chile. PUC Engineering is looking at ways to further build its external connectivity and take students' learning into the community.
- **'care' for students.** Since 2018, PUC Engineering has placed an increasing focus on 'care' for students – through offering personal support and establishing an 'emotionally safe' environment for learning – with a line item of the school's budget dedicated to these activities. The school's Engineering Education Unit is also conducting research into the 'care' practices currently delivered by the school and how these might be developed in the future. The experience of COVID-19 and emergency teaching has brought the issues of students' mental health into sharp focus and interviewee feedback suggested that the issue of 'care' for students would only become a more prominent component of the school's approach in the future.
- **graduate attributes.** The school is considering a reform to its stated graduate attributes, with a new and explicit focus on building students' resilience and ability to navigate uncertainty and change in both their personal and working lives.

Source of evidence

The case study for PUC (including Part A, the review of the Engineering Challenges course, and Part B, this review of the 'institutional context') drew upon one-to-one interviews with 12 individuals: PUC Engineering Dean; the PUC Engineering Director of Engineering Education; two leaders from the Engineering Challenges course; and eight PUC Engineering undergraduates (which included four undergraduate teaching assistants).

Further information about the methodology for development of CEEDA case studies is given at the project website[1].

[1] CEEDA case study structure and approach: https://www.ceeda.org/about#case-studies

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.

https://www.ceeda.org/