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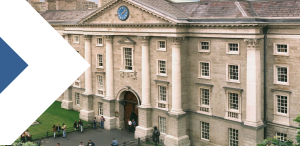
Digital education in the disciplines:

A snapshot of digital teaching, learning & assessment practices in Science, Technology, Education and Mathematics

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Purpose of this report

This report has been written as part of Trinity College's Digital by Design project, funded by the Irish National Forum for the Enhancement of Teaching and Learning. The Digital by Design project aims to build capacity for digital education across the disciplines within Trinity College, building on what we have learned from our pandemic experiences of digital learning.

The purpose of this report is to provide a snapshot overview of digital teaching, learning and assessment practices within the Health Sciences disciplines, including those within Trinity and across the broader national and international higher education sector. By profiling and disseminating these practices, this report aims to support and inspire academics and those with teaching responsibilities at third level to enhance digital teaching and learning practices within their disciplines.

Definition of Terms

For the purpose of this report, we have taken commonly used terms to have a particular meaning as follows:

Blended learning refers to learning that integrates complementary face-to-face learning experiences with online learning experiences.

Digital assessment is an assessment approach or process which is enabled by digital technologies. This includes:

- assessments which are fully enabled by digital technologies and often defined by their use of technology—such as blogs, wikis, online discussion fora, virtual simulations, multimedia artefacts.
- more traditional assessment types, elements of which are now often enabled using digital technologies—such as essays, annotated bibliographies, presentations.
- assessments which have moved into a digital context due to Covid-19, but may also be undertaken in traditional face-to-face formats—such as performances or debates (Academic Practice, 2021).

Digital learning refers to the use of digital technologies to enable and/or facilitate learning and teaching experiences, activities and processes. Digital learning encompasses a wide variety of learning models and approaches including blended, hybrid, hyflex or online learning.

Hybrid learning refers to modules or programmes that can be taken simultaneously by online and on-campus students working together as a single cohort. Also called "hybrid-flexible" or "hyflex" learning.



Hyflex learning combines the terms ‘hybrid’ and ‘flexible’. Often used interchangeably with the term ‘hybrid learning’, students have a choice in how they participate in the module—in the classroom or online or both.

Online learning is any form of learning which is facilitated wholly via the internet, encompassing both asynchronous and/or synchronous activities.

Pedagogy, defined broadly, refers to the practice of teaching and its associated discourse of educational theories, values and evidence (Alexander, 2009).

With thanks to:

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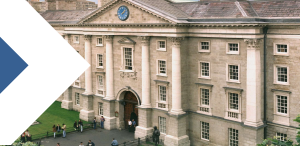
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Foreword

The enforced closure of university campuses, in response to the Covid-19 pandemic, has placed digital learning at the heart of higher education. For many it has led to the re-invention of teaching, learning and assessment practices across the disciplines, taking advantage of the affordances of digital technologies. In a short period of time, educators across the sector have developed core pedagogic competencies in digital teaching and learning, competencies which have long been deemed essential for a digital age (National Forum, 2015).

However, while the pandemic led to significant pedagogical innovation in some programmes, it has also presented many challenges. For many educators, time pressures and limited experience of digital pedagogies resulted in a “quick-fix” whereby long-standing pedagogies (often dominated by traditional lecture delivery) were rapidly moved online (Academic Practice, 2022). In addition, the necessity to deliver programmes remotely presented challenges for educators and students, with particular difficulties emerging for pedagogies supportive of experiential, laboratory, and work-based learning.

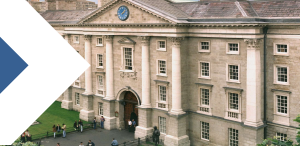
Recognising these ongoing challenges and the clear need to build digital pedagogic capacity at personal, disciplinary and organisational level, the Digital by Design project was developed with the intention of:

- equipping educators with core pedagogic competencies for digital learning, teaching and assessment;
- enabling the development of differentiated digital learning strategies which address discipline-specific competencies;
- building and supporting disciplinary Communities of Practice focused on digital education within cognate fields.

This report, authored by Research Assistants within the Digital by Design project team, was written as part of the initial research phase of the project and is one of three research reports, each of which focuses on disciplinary pedagogies within the three Faculties at Trinity College: Arts, Humanities & Social Sciences (AHSS), Science, Technology, Engineering & Mathematics (STEM) and Health Sciences. With a focus on AHSS disciplines, this report provides a snapshot overview of digital education practices in research-intensive universities within Ireland and internationally, particularly those practices enacted during the emergency pandemic “pivot” to online delivery.

I would like to thank our Research Assistant, Louise and Academic Developer, Caitríona, for their commitment and professionalism while researching and writing this report. We are more convinced than ever that if we are to build on what we have learned during the pandemic, guidance and support on the effective design and development of blended and digital learning is essential. Providing an insight into the practices and experiences of other AHSS educators during the pandemic, we hope that you find this report useful in informing your own pedagogic practices as we move beyond emergency delivery towards a post-pandemic “normal”.

Dr. Pauline Rooney, Digital by Design Project Lead



Introduction

The COVID-19 pandemic led to the closure of physical campuses across the globe, with universities and institutions rapidly adopted online teaching and learning practices (Bryson & Andres, 2020). The unprecedented transition was a stressful time for educators as they navigated the realm of online learning, some for the first time (Lishchynska & Palmer, 2021). Although institutions provided digital platforms and resources for their teaching staff, it was the responsibility of educators to adapt their teaching for online delivery (Klein et al., 2021). As time progressed, most higher education programmes have implemented a blended learning approach, availing of both in-person and online teaching (Brown & McCall, 2021). Online learning itself has often been perceived as an alternative educational model in comparison to in-person learning. As online learning continues to become an accepted model of education in its own right (Morris et al., 2020), it is important to reflect on the ‘lessons learnt’ during 2020.

This report provides a review of digital teaching, learning and assessment in the higher education sector in STEM, particularly in the context of the emergency “pivot” to online delivery during the pandemic. Although not wholly comprehensive in its scope, this report aims to provide a snapshot of the current landscape of digital TLA practices within STEM.

This report aims to:

- identify current and emerging practices in digital teaching, learning and assessment within STEM disciplines at Trinity, nationally and internationally, inclusive of in-person, blended, hybrid/hyflex and online approaches;
- gain an insight into the effectiveness of digital TLA approaches in STEM disciplines, and their limitations and challenges;
- explore student and staff perspectives on, and experiences of digital teaching, learning and assessment in STEM, particularly in the context of the pandemic period;
- reflect on implications for teaching, learning and assessment in STEM over the longer term, and, in particular, how institutions might support staff to develop and innovate in digital education provision.

Methodology

A desktop research methodology was adopted for the purposes of this report, with a focus on research-intensive national and international universities. Due to the emerging and evolving nature of many digital TLA practices, university sources constituted the primary focus of investigation, including institutional repositories, websites and institution-affiliated news sources (for example, blogs and online newspapers). For consistency during the research process, information was collected for those disciplines within the STEM Faculty at Trinity College Dublin.

A search string was composed using key terms relating to digital teaching, learning and assessment within STEM disciplines. Inclusion criteria were limited to articles and/or digital TLA projects conducted after 2015 that were available in English. Sources were included if they related to digital TLA practices implemented in the higher education sector of the STEM disciplines, inclusive of in-



person, blended, hybrid, hyflex and online approaches. Journal databases such as SpringerOpen were also consulted. All examples of digital TLA practices were compiled within a Microsoft Excel spreadsheet and sorted according to the pedagogical strategy underpinning the activity (for example, problem-based learning, team-based learning, etc.). The sections that follow provide an overview of our key findings.

Teaching & learning practices/signature pedagogies in STEM

When exploring digital TLA practices within any discipline, it is useful to consider underpinning teaching and learning practices or signature pedagogies. The term ‘signature pedagogy’, coined by Shulman (2005), refers to the forms or styles of teaching that are common to specific disciplines, areas of study, or professions. Signature pedagogies are defined as “the types of teaching that organise the fundamental ways in which future practitioners are educated for their new professions” (Schulman, 2005, p. 52).

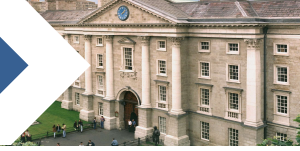
The STEM disciplines employ a wide range of pedagogical approaches to meet the intended learning outcomes. Some key pedagogical approaches include lab-based learning, project-based learning, problem-based learning, and fieldwork.

Lab-based learning

Lab-based learning is a practical pedagogical approach set in a laboratory environment. Students carry out practical experiments in order to apply and enhance existing knowledge surrounding a topic whilst also improving skills such as critical thinking, technical writing & collaboration. Lab-based learning appears throughout the STEM disciplines. Lab-based learning can take different forms, for example, the use of traditional lab experiments where students follow a defined set of procedures and a specific outcome is expected by the educator; or as an inquiry lab where students conduct open-ended experiments to make their own contribution to their field of interest; and finally project-based labs in which student undertake a specific project to work on over a period of time (Gravelle & Fisher, 2012).

Project-based learning

Project-based learning is an inquiry-led approach where learners apply and acquire knowledge through accomplishing projects and developing tangible products (Kuppuswamy & Mhakure, 2020). The creation of these artifacts distinguishes project-based learning from problem-based learning and other learner-centred pedagogical approaches (9). Project-based learning provides students with the opportunity to work collaboratively on real-world projects to develop their team-working abilities and critical thinking skills, in addition to developing the skills required to work in their respective STEM professional field (Kuppuswamy & Mhakure, 2020).



Problem-based learning

In problem-based learning within STEM disciplines, students are tasked with solving a specific question or problem over a period of time. Problem-based learning aims to solidify topics covered within the module, with students building on knowledge acquired in class. The approach is student-centred and prioritises active learning. Problem solving sessions usually occur in two forms; live sessions with students work separately or collectively under the educator's supervision, or working outside of class hours (Klein et al., 2021). Inquiry-based learning strategies such as project- or problem-based learning are key pedagogical approaches across the STEM disciplines (Gravelle & Fisher, 2012; McLain, 2021; Lucas & Hanson, 2014).

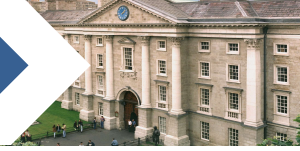
Fieldwork

Outdoor fieldwork is a long-standing pedagogy within the Life Sciences, such as Geography and other disciplines. Fieldwork has a range of benefits for students, such as promoting employability in the professional field, fostering transferable skills through peer collaboration, and connecting concepts learnt in a classroom to a real-life context (Kim, 2020).

Opportunities & challenges of digital/online/remote delivery in STEM

As the COVID-19 pandemic has led to an accelerated integration of online learning in higher education, STEM programmes have shifted from traditional methods of education, such as in-person laboratory sessions, to mainly self-directed learning facilitated by digital tools (Van Nuland et al., 2020). In 2020, STEM educators documented their experiences of facilitating emergency remote learning, with educators expressing their uncertainty regarding the most appropriate digital tools to use, the optimum proportion of blended delivery, or whether education should be delivered synchronously or asynchronously (Bryson & Andres, 2020). Developing an online curriculum can be time consuming for educators and requires a familiarity with online pedagogy and instructional tools (Asgari et al., 2021). Many educators had no prior experience of using digital tools in their teaching practice before the COVID-19 pandemic. Additionally, they had limited time and resources to deliver a comprehensive online learning environment for students (Bryson & Andres, 2020).

Similar to traditional learning approaches, online learning has its own unique challenges and opportunities. In a 2020 survey with Engineering students at an American university, nearly two thirds of students reported a lack of communication from educators as negatively impacting their online studies (Asgari et al., 2021). Over half of these students reported Zoom fatigue or difficulty maintaining focus in online classes. Furthermore, 55% indicated feeling socially disconnected from their peers, and 64% experienced a lack of engagement with online classes. A lack of motivation, reduced interaction with peers and educators and difficulty focusing were repeated issues emerging in numerous surveys evaluating students' experiences of online learning last year (Academic Practice, 2022; Xiong et al., 2020; Student Services, McGill University, 2020; Office of the Provost, Massachusetts Institute of Technology, 2020).



Some educators had previously thought that an online environment was not suited for teaching in certain STEM disciplines. For example, mathematics requires understanding of difficult concepts and theories which can be difficult to convey even in a face-to-face context. Therefore, for some mathematic educators, online learning was not viewed as an effective method of delivery, particularly for more complex modules and programmes (Lishchynska & Palmer, 2021). Additionally, the interactive nature of STEM disciplines, where educators and students provide continual feedback to each other in classes and tutorials was not seen as replicable in an online setting (Lishchynska & Palmer, 2021). Online lectures have often been regarded as less interactive than in-person lectures (Sandrone et al., 2021). Educators reported issues with using live video systems, such as Teams or Blackboard, and a lack of visual cues affecting interaction and student engagement (Kennedy & Littlejohn, 2020, Academic Practice, 2022). In 2020, an Irish university reported that postgraduate mathematic students found online learning more difficult than undergraduate students (Lishchynska & Palmer, 2021). This may be attributed to the higher complexity of concepts taught in postgraduate programmes or the level of educational experience impacting on a student's perceptions of online learning (Lishchynska & Palmer, 2021).

A repeated concern for STEM educators transitioning to online learning was the delivery of lab-based learning. There are a number of tools, equipment and materials available in labs that cannot be sourced or easily substituted in an off-site setting (West et al., 2021). Certain laboratory sessions may be hazardous to perform outside of a functioning lab. Another aspect of STEM curricula that is difficult to replicate in an online environment is the field trip. Hands-on, experiential learning is essential for STEM students to gain professional experience skills and to be prepared to join the workforce (Galoyan et al., 2019). Additionally, experiential learning is recognised as a means of improving students' knowledge retention (Freeman et al., 2014), therefore impacting on their ability to achieve intended learning outcomes.

While there are challenges to implementing online learning, there are a range of benefits to incorporating digital learning into practice. STEM students have commented on the flexibility of learning when using pre-recorded material, particularly when digital tools allowed students to pause and re-wind content (epsplacementblogs, 20 May 2021). Online learning allows for synchronous or asynchronous delivery, providing greater flexibility for students to guide their own studies, in addition to providing education to students who do not have access to a physical campus (Hastuti et al., 2021). For those students who may be hesitant to speak in front of an in-person class, it also provides opportunities to engage in discussions via online fora (Hastuti et al., 2021).

There has been a significant push in recent years to implement experimental and active learning as a core component of the STEM disciplines, which has been impacted by the transition to online learning (Sandrone et al., 2021; West et al., 2021). It could be suggested that implementing the use of certain digital tools, which centre the learner's experience, could help achieve this goal. An issue with physical laboratory sessions is that when large student groups are performing experiments simultaneously, they may not achieve the expected learning outcomes due to a lack of individualised learning (Achuthan et al., 2021). An online learning environment can facilitate a larger number of students compared to a physical environment and can make it easier to track the individual progress of students. Additionally, an online lab does not have the same time constraints of a typical in-person lab, which enables open-ended explorations that were previously not possible (Brancaccio-Taras et al., 2021).



Digital teaching, learning & assessment in STEM

It is recognised that there were varied levels of preparedness for the pandemic move to online learning, with some institutions that had previous experience of online delivery reporting quicker transitions (West et al., 2021). With the proliferation of smartphones and educational platforms, such as online laboratory programmes, there has been an increase in the use of digital tools in STEM education (Klein et al., 2021). However, pre-pandemic, the use of digital TLA practices in STEM varied significantly across disciplines and universities globally.

During 2020, STEM educators availed of both synchronous and asynchronous modes of learning. Synchronous learning was typically facilitated through videoconferencing platforms, such as Zoom, Google Classroom or Microsoft Teams (Tyaningsih et al., 2021, Academic Practice, 2022). Asynchronous learning can be conducted through sharing pre-recorded content on a university's VLE, emails, and discussion forums. Synchronous (e.g. live online examinations conducted through an online platform) and asynchronous (e.g. take home exams) methods of assessment were also conducted (Asgari et al., 2021). Online assessment practices in STEM also included open-ended exams and multiple choice exams (Chierichetti & Backer, 2021). One study on digital assessment for Engineering found a preference for open-book exams, in comparison to closed-book assessments, which decreased the need for proctoring tools (Asgari et al., 2021).

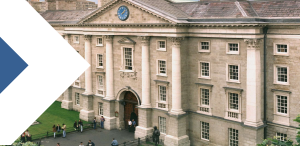
A flipped classroom approach was implemented in several universities, where educators circulated material, such as YouTube links, pre-recorded content or online articles, in advance of an online class (Pokhrel & Chhetri, 2021). The class time was then allocated for student discussion and peer activities based on the previewed material.

Some STEM educators embraced the possibilities offered by online learning. The following section presents STEM case studies which highlight innovative methods of online learning, with particular focus on the transition to online learning in early 2020 and beyond.

Exemplars

Project-/Problem based learning

In 2020, educators adapted inquiry-based projects from in-person to an online setting. Due to the pandemic, educators at University of Pennsylvania's Department of Mechanical Engineering and Applied Mechanics (MEAM) redesigned an 'Intro to Robotics' course for undergraduate students, so that all work was completed online (Pappas, 2021). In the course, students got their first glimpse into the professional field by programming a physical robotic arm in numerous exploratory lab sessions. A virtual simulator was developed to replace the physical version. However, the educator noted significant differences in working with an online simulator, in comparison to a 'real' robot. The motions of a real robot were controlled by programmed code, which was constrained by the physical environment. While this can be replicated in an online environment, it was difficult for students to visualise what the programme code represented in the real world. Students encountered bugs within the simulator which stopped correct code from functioning. Although, the online format created new challenges to collaborative learning between students, the simulator



allowed for student engagement with their educator that an in-person course did not provide. The educator implemented a final group project, a block-stacking competition using the robotic arm, to encourage student collaboration, which received positive feedback. The students found the simulation was good practice for problem solving in future academic or industry placements.

Lab-based learning

As stated previously, facilitating lab-based learning was a focus point during 2020 for STEM educators. While access to a physical campus was limited, educators developed projects that students could partake in remotely. Development of these projects focused on process skills as opposed to demonstrating hands-on skills (Slade et al., 2021). Three common approaches evolved in conducting remote labs; the use of recorded experiments, virtual labs, and at-home experiments (Shivam & Wagoner, 2020).

Recorded experiments

Some educators recorded video demonstrations of lab procedures and made these available for students through their university's virtual learning environment (VLE). In some of these cases, students who needed additional help were provided individual or group mentoring sessions on-campus home (West et al., 2021).

In the Design Engineering for Physics students (DEPS) course at Delft University of Technology, workshops were moved online halfway through the year (Hut et al., 2020). Teachers decided to curate a YouTube playlist depicting the educator's pre-recorded instructions and to set up a Discord community for two-way communication between the teacher and students. At the start of each workshop, students were provided a Jupyter template to guide them through the day's schedule and for students to complete written submissions. 'Sanity check' assignments were circulated daily to students via the VLE, for Teaching Assistants (TAs) and teachers to assess whether a student was on schedule and engaging with the assignment. Informal feedback indicated students appreciated the clear, defined structure of the workshops. The short videos were found to be more effective than long lectures or class manuals. Students used creative solutions to complete the assignments. However, as the students didn't work in groups, which would usually occur in a workshop, the grading load for the TAs increased. Due to this, the final assignment was a group project.

In other institutions, students produced their own videos for assessment purposes. In one institution in 2017, Chemistry students recorded themselves conducting experiments, verbally explaining their actions to demonstrate their knowledge of different techniques (Mariani et al., 2021). The narration aspect was a learning curve for students who were used to submitting written examples of their acquired knowledge. By recording the experiments, students produced a digital artefact to highlight their lab expertise. The project incorporated peer review, with students offering each other feedback on their videos. However, it was noted that the use of recorded experiments as a substitute for in-person lab experiments resulted in students learning through observation of their educator only, instead of gaining own hands-on experience. For certain STEM disciplines, such as Engineering, this may make it difficult to achieve intended learning outcomes.



Virtual labs

Other solutions included using virtual lab simulations (MacKay, 2020). Virtual labs allow students to gain an understanding of real-life experiments in a simulated environment, preparing students for in-person training and research in lab environments (Ray & Srivastava, 2020). Certain institutions employed digital software tools specifically designed to provide a virtual laboratory environment for students. At California Institute of Technology, a Physics educator turned to LabVIEW, a software platform and programming language used for interacting with experimental hardware via a computer, to provide students with access to the tools and techniques usually encountered in a lab (Moseman, 2021). Each student installed the university-acquired software on their own computers and were given a data acquisition device that allowed students to measure audio signals. Students submitted their LabVIEW files for assessment through the University's VLE, with the majority of lab work occurring asynchronously.

At-home experiments

One of the most popular approaches for remote labs was at-home experiments. Educators sent out lab projects that incorporated technologies easily available to students at home (West et al., 2021). One strategy involved requesting students to perform synchronous lab procedures in Zoom breakout rooms, with a teaching assistant observing students' performance (West et al., 2021). Smartphones were found to be particularly useful when conducting lab experiments, due to the range of analysis tools and sensors available (O'Brien, 2021), including sound meters, accelerometers, magnetometers, proximeters, gyroscopes, photometers, cameras, GPS, and barometers (Vieyra et al., 2020). Some students, such as Chemistry students based at the University of Birmingham, conducted 'at-home labs', using household items to conduct experiments, with additional equipment provided by the institution (epsplacementblogs, 20 May 2021). Students enjoyed the independence afforded by the at-home labs, with students investigating their own hypothesis as opposed to following traditional lab instructions.

Several STEM educators provided the materials needed for students to conduct projects at home (We are Engineering, University of Bristol, 10 December 2020; Zewe, 6 May 2020; Pardasani, 2021). For instance, the Engineering department at the University of Bristol posted at home lab kits to students (We are Engineering, University of Bristol, 10 December 2020). The kits were designed to last for the duration of the student's degree, with a mixture of high and low-tech components. These kits included drawing and measurement tools, electronic equipment such as prototyping boards, microcontrollers and wire cutters, and Lego®. Following anecdotal evidence of the kits encouraging creative and independent learning, the institution remains open to continuing this practice for future students.

At Harvard University, Engineering students were provided at-home kits to conduct lab sessions off-campus (Zewe, 6 May 2020). Kits included resistors, capacitors, integrated circuits, microcontrollers, wire cutters, and a multimeter. Students used these tools when participating in live Zoom sessions, under the guidance of their lecturer. Students used online platforms such as Zoom and Slack to cross the physical divide when collaborating with each other. However, some students in certain STEM disciplines did not find the experience 'authentic' as the kits provided



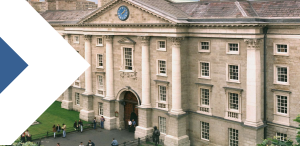
were not adequate substitutes for machines and tools that would be available in-person (West et al., 2021). Educators found interpreting data significantly different in online labs compared to in-person classes, as there are chemical phenomena that cannot be observed online without access to devices and tools (for example, pH meters, temperature and pressure sensors, etc) (West et al., 2021). Other challenges included ensuring that students had access to fully functioning components, particularly in cases where there was no access to equipment to fix faulty devices (Pardasani, 2021). To resolve this, online platforms were set up for students and teaching assistants to brainstorm solutions for issues with broken equipment (Pardasani, 2021).

Fieldwork

Due to travel restrictions globally, the majority of fieldwork trips for STEM students were cancelled in 2020. Educators turned to digital tools to provide students with an immersive learning environment in order to facilitate achievement of the same learning outcomes.

Prior to Covid-19, students in an undergraduate Life Sciences programme at Imperial College London typically conducted in-person fieldwork related to their studies – fieldwork which was subsequently cancelled in response to the COVID-19 pandemic (MacKay, 2020). As an alternative, the Department offered a ‘Virtual Field Course’ which included group activities, fieldwork, lectures, and data-focused projects to be undertaken over the summer break in 2020. One of the first projects, the ‘Dawn Chorus’, involved students across the globe recording birdsong in their local area using their smartphones, noting certain variables, for example, time of day, weather conditions, etc. (MacKay, 2020). Using the collected data, species diversity was compared across a range of international habitats. In addition to this, the University facilitated a range of virtual fieldtrips for STEM students. For example, third year Geology students who were unable to take a trip to Sardinia were provided a ‘virtual Sardinia,’ developed by their course leaders (Wilkes, 29 May 2020). This was developed using the game engine Unity and allowed students to inspect 3D models of real rocks in a virtual space. The virtual fieldtrip followed the structure of an in-person fieldtrip, consisting of taught fieldwork at the start of the day and self-conducted fieldwork in the evening, allowing students based in Asia to participate despite the physical distance. The virtual space was supplemented with Google Maps photographs, an AI demonstrator, and a virtual microscope to examine the rocks in detail.

Educators turned to popular, familiar, digital technology to produce virtual spaces for students to learn from. Zoology students based in the School of Biology at the University of Edinburgh usually travelled to FSC Millport on the island of Great Cumbrae, sampling flora and fauna (Little, 12 January 2021). In response to COVID-19 barriers, educators created a virtual island using the popular video game Minecraft to replicate the real-life five-day fieldtrip. Educators wanted to allow students to be creative and work independently. Educators used Open Street map data for Puerto Rico, modifying it to create four separate beaches with distinct animal species in each zone. The island included an ‘Eco Lab’ for students to perform experiments on food choice with virtual animals. Educators recognised the importance of creating engaging content in fully realising the benefits of gamification in education, by including ‘decorative elements, secrets, train networks, and a host of custom achievements’ (Little, 12 January 2021). While these additional elements were not necessary to completing the learning outcomes, it added depth to the virtual world experience.



A handbook was circulated to students and in-game signs and screen prompts provided the scaffolding for learning for students. The virtual fieldwork could be an individual or group-based exercise, with plans to develop a server for students to collaborate synchronously in future programmes.

Moving forward

The COVID-19 pandemic has significantly altered how teaching and learning is conducted. Recalling their experiences of emergency online teaching, STEM-based educators have noted that online teaching is not simply a replacement of in-person teaching and should not be attempted or treated as such (Bryson & Andres, 2020). It is frequently emphasised that emergency remote teaching is very different to intentionally designed online TLA practices (Hodges et al., 2020). Many of the challenges encountered partially resulted from the limited time available for preparation and a lack of alternative options. Online learning requires detailed planning and development which was not feasible within the short time frame educators had in 2020. Students reported experiencing a number of challenges with online learning. Zoom fatigue, a lack of peer support and a lack of clear guidance from educators decreased motivation to participate (Asgari et al., 2021). It was suggested most of these issues could be resolved by breaking long lectures into short segments with frequent rest breaks, developing a clearly defined and structured course plan, providing opportunities for peer interaction and collaboration, and circulating recordings of live lectures to allow students to learn at their own pace (Asgari et al., 2021).

While several educators and students reported positive experiences of online teaching and learning, as evidenced in our Exemplars section of this report, it remains unclear how online TLA strategies will be implemented moving forward. For instance, repeated concerns regarding academic integrity could act as a deterrent for utilising online assessments in the future (Chierichetti & Backer, 2021; Hsu, 2021). It should be noted that a number of educators involved in the case studies highlighted within this report stated their intention to embed the digital projects within the formal curriculum in recognition of the positive learning outcomes achieved and the potential of online TLA strategies (We are Engineering, University of Bristol, 10 December 2020; Little, 12 January 2021). While for some students a blended approach was preferred over a fully online learning experience (Lishchynska & Palmer, 2021), other students were more hesitant and proposed a number of changes if blended learning was to continue in the future (Tyaningsih et al., 2021). These requirements included appropriate deadlines for assignments, no more than 50% of the curriculum to be delivered online, and a flipped classroom approach to be implemented, using video and audio media resources (Tyaningsih et al., 2021).

It is important to note that the effectiveness of education provision is also dependent on a reliable infrastructure that operates to support both educators and learners (Asgari et al., 2021). While many STEM educators availed of multiple digital tools to offer an effective, interactive learning experience for their students, the availability of these tools was dependent on institutional funding and resources. Additionally, it is increasingly recognised that developing modules and programmes that capitalise on the affordances of digital technologies will involve not only the ‘teaching educator’, but also a team of experts including educational/learning designers, learning technologists, technical support staff etc. If institutions are to build on the learnings of the past two



years and sustain pedagogical gains, institutional commitment to, and guidance on, the effective design, development and implementation of blended and digital learning for STEM education will be essential.

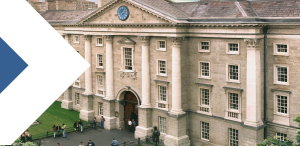


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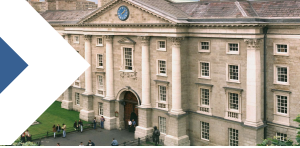
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Appendix 1: Digital teaching, learning and assessment practices in the STEM disciplines

Pedagogical Approach	University	Discipline	Aims	Method	Observations (Challenges/Strengths)
<i>Lab-based learning</i>	University of Edinburgh	Science	Using video demonstration and peer-feedback to develop lab-based skills (Mariani, 2021).	155 first year Chemistry students watched videos demonstrating correct techniques (titrations, distillations, and preparation of standard solutions) prior to an online tutorial. Afterwards, students were asked to record themselves performing two of the techniques. The videos were submitted for assessment and received peer and educator feedback.	Educators intend to extend this and build a framework of techniques that students can build up over the course of their degree. A pilot of a technique was run for second year students in 2017.
<i>Lab-based learning</i>	Imperial College London	Engineering	Using augmented reality tools, such as Microsoft's HoloLens technology, controllable cameras and QR codes, to delivery lab-based teaching (MacKay & West, 17 May 2020).	More than 600 students in 69 countries took part. One member of each group was physically present in the lab and streamed what they were doing via the HoloLens headset to the rest of the group. Cameras were placed in the lab and streamed content continuously which students could access at their own pace. Students could control these cameras (i.e., zoom in and out to capture readings on equipment). QR codes were placed to allow students to easily access information regarding their tasks both remotely and in person.	One student said that these labs provided greater flexibility and that the lab experience was enhanced.
<i>Lab-based learning</i>	TU Delft	Engineering	Investigate how a typical hands-on undergraduate	In the 'design engineering for physics students' (DEPS) course for second year	Educators noted that short instruction videos work much better than longer



Pedagogical Approach	University	Discipline	Aims	Method	Observations (Challenges/Strengths)
			course has been transformed into a home-based course (Hut et al., 2020).	freshmen, the day workshops were moved to a virtual environment halfway through the course due to Covid-19 lockdowns. Students were asked to view recorded instructional videos on YouTube and use the two-way online communication platform 'Discord'.	lectures or tedious manuals. Students took the course seriously and often came with creative solutions for their home assignments. More freedom for the home assignments necessitated stricter guidance of the process and (online) grading was labour intensive, leading to the recommendation that it should be simplified as much as possible.
<i>Lab-based learning</i>	National University of Singapore	Science	Facilitating home-based learning for students (Alumnus, 2021).	Physic department staff members created shoebox kits for students to conduct experiments at home. A sample kit included a compass, magnet, ruler, and metal plates which allowed students to measure magnetic fields, aided by a mobile app. Another kit for a solid state physics module used ping pong balls to create 3D arrangements of atoms.	Not all labs can be conducted at home for safety reasons or due to need for bulky lab equipment. The kits made labs sessions more interactive. For demonstrations involving small items, Zoom facilitated greater visibility and accessibility than a large lecture theatre – as a result, the educator considers this practice could be continued post-pandemic.
<i>Lab-based learning</i>	MIT	Engineering	To adapt existing labs for at-home (MIT Department of Mechanical Engineering Meche, 11 November 2020).	The educator, who was alone in on-campus laboratories, conducted online demonstrations to show students how to control and utilize lab-based equipment.	Feedback was positive and the lecturer found the online lab sessions to be almost as effective as the on-campus labs. However, the remote lab requires one person to be physically present in the lab to facilitate tasks such as tilting and changing samples.



Pedagogical Approach	University	Discipline	Aims	Method	Observations (Challenges/Strengths)
<i>Project/ Problem-based learning</i>	University of Pennsylvania	Engineering	To create a robotics course in an online setting (Pappas, 24 February 2021).	<p>Faculty members developed software which acted as a virtual simulator where students could create robots and implement code to make them move. The simulator allowed students to turn on and off real-life phenomena (e.g., gravity), allowing for greater control and creativity.</p> <p>The software was given to 80 students for free to allow them to take part in these labs from home. For support, students could reach their educator via virtual office hours.</p>	<p>The intended learning outcomes were achieved. The online format facilitated certain forms of student engagement that in-person learning could not. However, educators found it difficult to encourage student collaboration, which was unusual based on how the course operated in-person previously. The software had bugs, which was a source of confusion for some students when writing code.</p> <p>The department plan to incorporate the simulator into an in-person version of the course.</p>
<i>Fieldwork</i>	Imperial College London	Science	To generate an online environment whereby the geology students could virtually carry out their fieldwork (Wilkes, 29 May 2020).	The lecturers developed an app using a game engine (Unity) to enable students to explore 3D outcrops. The virtual environment was accompanied with high-resolution photographs, 3D images of rock samples and a virtual microscope to analyse rock sections.	The virtual world allowed students to study some localities that they wouldn't be able to in-person.
<i>Fieldwork</i>	Imperial College London	Science	To substitute a fieldtrip for postgraduate students to the Pyrenees with a simulated trip (MacKay, 23 April 2020).	The group stuck to a regimented 'fieldwork' schedule, as they would in a physical setting. The staff and Teaching Assistants would take 'stops' during the trip using MS Teams. Students were	The detailed photos allowed students to observe more than they usually would in person. Sessions were recorded and back-up exercises were developed to avoid any technical or



Pedagogical Approach	University	Discipline	Aims	Method	Observations (Challenges/Strengths)
				assigned tasks, interpreting evidence using hi-resolution photographs, Google Earth, and drone-scanned virtual models of geological formations.	personal issues impacting on achieving the learning outcomes. The Teaching Assistants found it difficult to demonstrate without having in-person contact. While the trip was successful, the educator is looking forward to physical fieldtrips in the future.