DESIGNING A RESILIENT CURRICULUM FOR A JOINT ENGINEERING FIRST YEAR

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ABSTRACT

In March 2020, the University of Bristol in the UK was in the middle of the development of a new curriculum for a joint first year of 4-year undergraduate Engineering degrees for introduction in September 2021. This curriculum was designed using constructive alignment principles informed by significant student and staff input. The focus was on skills development, challenge-led projects, and creativity for professional programmes. Assessment was rebalanced from mostly summative to mostly formative. The arrival of the global COVID-19 pandemic accelerated the rollout of this curriculum: the new approach had so many advantages for this challenging situation that its introduction was brought forward to September 2020.

This paper centres on the elements of the new curriculum which made it particularly resilient for the pandemic. The constructive alignment approach ensured that curriculum developers concentrated on the overall educational aims of the first year, rather than trying to fit the education into set forms and modes of delivery. The process of developing programme-level intended learning outcomes, followed by a process of paring down the content and assessment of the programmes to focus on these learning outcomes, resulted in a simplification of the structure of the programme. Delivery methods were greatly diversified and blended, allowing teaching to very large cohorts in a variety of situations. True team teaching with staff members developing content together (rather than delivering sequentially) meant that, for the first time, there was some redundancy in the teaching teams. These and other positive and negative aspects of the features of the curriculum in terms of adaptability in the pandemic are discussed in the paper.

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1 INTRODUCTION

1.1 Background

In March 2020, the University of Bristol was in the middle of the development of a new curriculum for a joint first year of many of its four-year undergraduate engineering degrees planned for introduction in September 2021. When the COVID-19 pandemic hit the UK, the new curriculum had so many advantages for this challenging situation that it was rolled out early in September 2020.

The impact of the COVID-19 pandemic on higher education around the world [1] to the challenges and opportunities that it offered [2] have already been described in the literature. Whilst these authors have taken stock of what has happened, others emphasise the need for 'reenvisioning' and 'reimagining' our higher education systems in the future. We need to ensure that our education systems are robust to pandemics and other types of adversity.

Recent recommendations for transitioning to life after the COVID-19 pandemic explicitly identify **resilience** as a necessary element [3]. Resilience in human development has been defined as 'positive adaptation in the context of significant adversity'. Previous work has looked at Universities as resilient organisations and define the construct of resilience "as the institutional capability to effectively absorb, respond to and recover from an internally or externally induced set of extraordinary demands" [4]. Pinheiro and Young use a complex systems perspective to identify three qualities desirable in Universities for resilience: 'slack' – a buffer of redundancies and resources, 'requisite variety' – a diversity of possible responses and lastly, 'decoupling' – a loose coupling between the entities in the organisation [5]. They also point out the difference between resilience planning and strategic planning: the former focusing on flexibility and having redundancy and resources, whilst the latter focuses on hierarchy and streamlining.

Chow, Lam and King have proposed useful ideas on crisis resilient pedagogy, suggesting that adaptability, creativity, connectivity (sharing resources), diversity and endurance are all attributes which teachers, students and administrators can apply to increase the resilience of their teaching methods [6]. Other authors suggest that preparing courses as suitable for delivery via multiple modalities: online, hybrid or face to face; engaging in projects with uncertain outcomes; working in groups to strengthen teamwork and networking and caring beyond the self will all contribute to encourage flexibility and creativity and to promote resilience [7]. In this work, we look at what features of a curriculum might make it resilient. But what are the possible types of adversity that a curriculum would need to adapt to?

1.2 Types of adversity

Whilst the list of possible scenarios includes social unrest, pandemics, war, natural disasters, shifts in political climate or demographics etc, the ways in which these events could affect curricula are more limited. Just as there are thousands of diseases,

but only a limited number of symptoms of disease. The possible effects of the adversity might include the following:

1. Numbers of students increasing or decreasing
2. Numbers of staff increasing or decreasing
3. Study conditions for students
4. Closure of facilities (such as classrooms and laboratories)
5. The movement of students away from campus (for campus-based Universities)
6. Changing preparation of students for study
7. Changing mental and physical health of students
8. Changing attitudes towards study
9. Changing relevance of skills and content taught
10. Demographic of students coming to study

It could be said that the coronavirus pandemic of 2020 affected UK universities in all but the last two of these ways. In the future, those beginning a process of curriculum reform could ask: how adaptable is our new curriculum going to be? Very little work has looked at how to make a curriculum itself resilient. Adaptability and flexibility do not generally go well with the rigidity of curriculum structures and timetabling. Are there features of a curriculum that we can consider during curriculum reform to promote resilience? This study looks at a particular example of a curriculum and which elements of it made it resilient and not resilient in the face of the COVID-19 pandemic.

1.3 Structure of the paper

Section 1 of this paper covers previous work in this area, the section 2 describes the context engineering at the University of Bristol and degree structure. Section 3 explains the drivers, process and a structure of the new curriculum, whilst section 4 describes the features of the curriculum that were particularly useful in the pandemic. Section 5, on the other hand, describes features that were challenging during the pandemic. The discussion in section 6 offers an application of some of the concepts of resilience to these features, whilst next steps and conclusions are outlined in sections 7 and 8.

2 CONTEXT

2.1 The UK system

The UK has a system of accreditation of higher education institutions for their engineering degrees which is carried out by professional engineering institutions, such as the Institution of Mechanical Engineers. The degrees must follow a specification and the Universities are regularly inspected by a team from the institution. This means that any curriculum change must be compliant to the institution’s specifications [8].

2.2 The University of Bristol

The University of Bristol is a research-led UK University with approximately 27 400 students and 7600 staff (data from 2019/20). It is a top five UK university for research and a top six European university for teaching, according to the Times Higher Education magazine in 2018. The courses are structured for students who have attained excellent grades in their final school/college exams in mathematics and sciences. In the school of Civil, Aerospace and Mechanical Engineering (CAME) in the Faculty of Engineering, approximately 650 students start 3 year (BEng) or 4 year (MEng) undergraduate degrees each year. These run as separate programmes for each engineering discipline, plus there is a more general programme in Engineering Design. Whilst very highly rated by students, the curricula in the first year of all these degree programmes had not been completely refreshed for several years and there were several reasons for redesigning the curriculum which are discussed in the next section.

3 DRIVERS AND PROCESS

3.1 Drivers

The University of Bristol mechanical, civil and aerospace undergraduate engineering degree programmes have not been subject to major review for many years. They had evolved piecewise via a series of changes to individual taught units in response to student feedback and periodic review for professional accreditation, but the overall structure of the programmes and their organisation had not been examined or revised. Simultaneously, the scale at which undergraduate teaching is delivered had grown significantly, with the number of students per year growing from around 200 to around 460. This resulted in some issues with the curriculum including:

1. Overassessment of students resulting in high student workloads
2. Low engagement with non-assessed activities
3. High marking and feedback load for staff
4. Poor interconnection between units and lack of interdisciplinarity
5. Many staff teaching units by themselves
6. An over-emphasis on science and mathematics at the expense of practical, professional and design skills

The school also wished to support the increase in the diversity of its student population and widen its participation, so a driver for curriculum change was to enable a smoother transition to university for all students.

A common structure of the first year for the range of engineering programmes was proposed to address some of these issues and to allow students to transfer between programmes easily in the first year so that they could make an informed decision on the discipline they have chosen to follow.

3.2 Methods and Process

The method by which the curriculum review was conducted, and some preliminary results is described in detail in another paper by the authors and is summarised in the diagram in Figure 1.[10]. This paper describes, amongst other things, how constructive alignment [9] was selected as being the most appropriate method for curriculum design for this particular context.

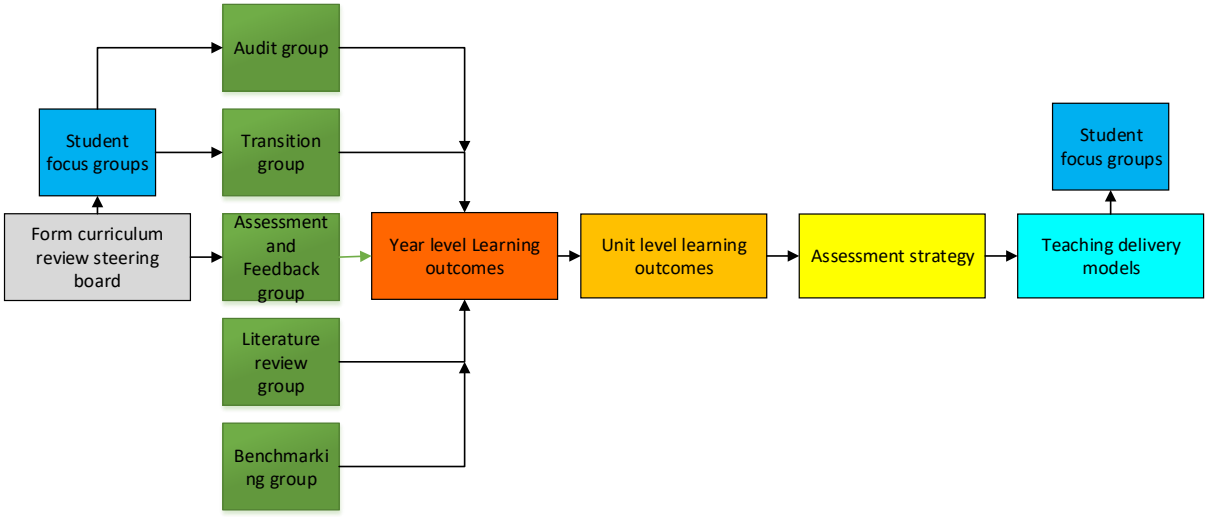

Figure 1: the process of curriculum review used by the University of Bristol [10]

The old programme structures were highly complex, with many different units (or modules), each of different credit value and each managed by a different department. Academics taught units individually and engineering science and mathematics comprised 80% of the old programme. The structure of the new curriculum contains a core of five units (Engineering Mathematics, Engineering Science , Engineering by Investigation, Engineering by Design, which are common to all programmes. This is shown in Figure 2. There is also one discipline-specific unit for each different discipline: 'Principles of Aero/Mechanical/Civil/Design Engineering'. In the new curriculum, Engineering Science and Mathematics now comprises 50% of the programme, with the introduction of new modules on skills (Engineering by Investigation) and on group projects focusing on global challenges (Engineering by Design).

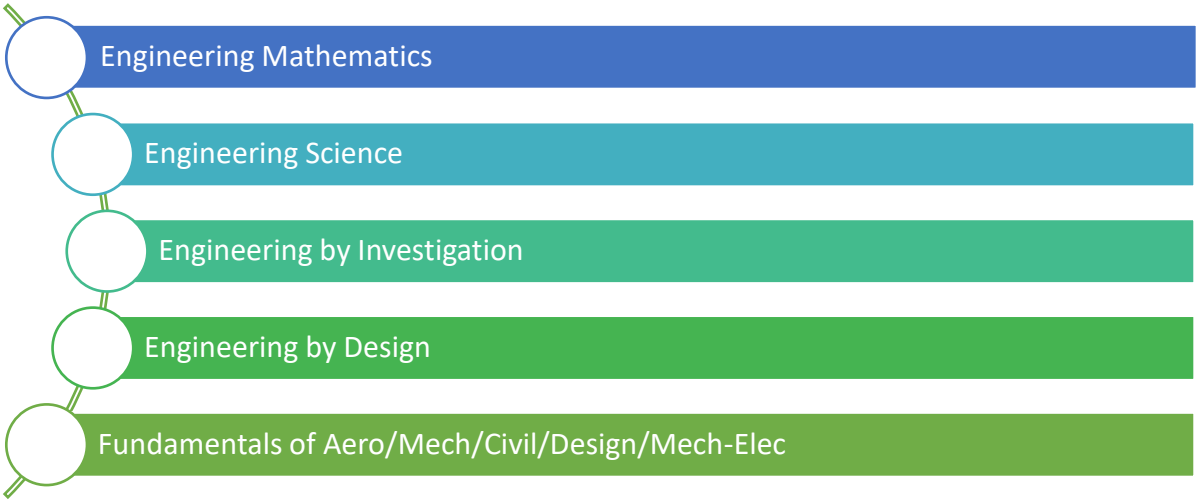

Figure 2: The simplified structure of the new first year curriculum

3.3 Monitoring and Evaluation

Feedback from students was (and continues to be) gathered from several sources: Staff-Student Liaison Committees for each programme of study were held at approximately bi-monthly intervals throughout the year, with students representing all years present; a "town hall" event after the Easter break specifically to discuss aspects of the new first year; the annual University student survey questionnaire, though these data will become available later in the summer. Assessment results data will also be used, when available, to gauge the progress of students against the learning objectives for them in the first year. To date, student feedback has been largely positive. Students enjoyed the opportunities to work in interdisciplinary groups: "*It was great to work with students on the other courses*". They also appreciated the multidisciplinary design unit and its timing: "*I liked the design unit – it was good to do this from the beginning*".

The use of formative assessments to encourage regular learning when operating remotely was highlighted: "*the tests were good to get me into the rhythm of working*".

On the negative side, students were frustrated by not being able to meet their fellow tutor group members in person and found studying the practical 'Engineering by Investigation' unit remotely, necessitated by public health measures, instead of in the Labs, particularly challenging: "*The lab unit is a good idea, but it didn't really work well online*".

In the following section, the features of the new curriculum which were suited to the difficult conditions of the pandemic are discussed.

4 RESILIENT FEATURES OF THE NEW CURRICULUM

4.1 Introduction

The following features were identified as contributing towards the decision to bring forward the curriculum review changes by a year. They all lent the new curriculum an adaptability and robustness to the various adverse effects of the pandemic in 2020.

4.2 Use of constructive alignment

The constructive alignment approach to curriculum review ensured that curriculum developers concentrated on the overall educational aims of the first year, rather than trying to fit the education into set forms and modes of delivery. The process of developing programme-level intended learning outcomes, followed by a process of paring down the content and assessment of the programmes to focus on these learning outcomes, resulted in the competing areas of content for the first year to be accommodated and reconciled.

4.3 Simplified structure

The simplified structure of the programme allowed a coherent delivery of the different Engineering Science topics with Engineering Mathematics phased to support the science. It also allowed better planning of formative and summative assessment. The clearer, more consistent structure reduced the burden on students of navigating many different academic expectations over a large range of units. In the fragmented, isolated world during the pandemic, this was particularly important, as students lost much of their peer support.

4.4 Standardised structure

Under the previous system, coordination of the many units provided by academics in several departments was difficult; when rapid change was demanded when remote working was necessary, it was difficult to do this effectively. The end of the secondary education of many of the students was badly disrupted and so sometimes their tacit understanding of how to plan and carry out their studies has been impaired. The standard structure made it much easier for students to appraise what is expected from them and what they needed to do to successfully complete the year. It also enabled more consistent support for students. Academic and pastoral support was targeted at specific activities throughout the year. The ability to plan these and generate appropriate resources helped transition activities like personal tutorials to function more effectively online.

4.5 An emphasis on skills

Practical laboratory content, previously embedded within the different science units, was now delivered in one ‘Engineering by Investigation’ unit. Whilst individual activities still support the engineering science theory, the emphasis was now on the techniques of conducting and reporting experimental practice. This decoupled the practical elements from the science units. A teaching team was specifically responsible for developing practical activities that the students could do both on-campus (when

allowed) and at home. This meant the skills teaching was as consistent as possible and not reliant on piecemeal implementation across multiple units.

4.6 Interdisciplinarity

A common design unit, 'Engineering by Design', introduced students to the processes of problem solving and design through group projects. The unit explicitly aimed to encourage interdisciplinary working from the very beginning of their studies. For the first five weeks of the course, students undertook an immersive mixed-cohort group project with a global challenge theme. The aim of mixing the cohorts was to enable students to make connections outside their specific discipline, strengthening their networks and peer support. In the pandemic this had the unforeseen advantage of increasing the pool of students available to work together and the network of possible connections.

4.7 Programmatic assessment

Designing the delivery pattern and diet of assessment at programme level allowed careful planning of the nature and timing of formative assessment across the year. This allowed students to plan their work effectively. A diverse range of assessment types were used to prepare students for the forms of assessment they would experience later in their degrees and for their professional careers in engineering. From the point of view of resilience, programme level assessment planning allowed careful resource allocation by both the University and students.

4.8 Reducing the emphasis on summative assessment

Excessive summative assessment was having negative effects on our students. Assessment was capturing a disproportionate portion of students' attention and displacing other learning. The curriculum review reduced the number of summative assessments and increased the number of formative assessments. This separated the periods of learning from the periods of summative assessment which meant time management and engagement were easier for students.

4.9 Team teaching

Previously, across the four programmes there were 22 different units in operation for the first year. This resulted in little team teaching and a very high administrative workload. There was therefore limited scope for the transfer of best practice and resources between similar units on the different programmes. If any staff member needed to be off work, then it was a challenge to ensure continuity of teaching. The team teaching occasioned by the curriculum review enabled some redundancy in the system. Team teaching also had a positive impact on staff mental health and reduced the potential for loneliness in remote working, as it provided clear reasons for colleagues to interact to plan and discuss their teaching and assessment.

4.10 Teaching delivery methods

A flipped classroom delivery system was implemented i.e. pre-recording video sessions in bite-sized chunks and then running live sessions either face to face or via video/Zoom depending on the lockdown status. This was found to be highly effective in the pandemic and with a diverse student body, with many students finding the flexibility and ability to 'rewind' the videos particularly useful. When students could attend in-person, some of the teaching was delivered in a hybrid format. This meant that students could attend a session either in-person or online. The success of this was mixed. It did successfully allow teaching on the same basis for all the students, no matter where they were. However, it was challenging to deliverfor the staff.

The last point illustrates that not all the features of the new curriculum were found to be positive in the pandemic. The next section discusses more challenging areas.

5 NON-RESILIENT FEATURES OF THE NEW CURRICULUM

5.1 Dependence on laboratories

As is the case for many STEM subjects, first year engineering courses rely heavily on practical and laboratory work to enhance understanding of the science and to develop skills and techniques. The new 'Engineering by Investigation' unit on measurement and instrumentation was planned as a key feature of the first-year curriculum. It was to be delivered through a series of on-campus practical activities. However, it was clear during the pandemic that almost all these activities could not run. The mitigation devised by the teaching team was a range of home lab activities. These were supported by a University-supplied kit of components which were sent out to students around the world. By their nature, these were small scale activities, so the more substantial supporting experiments had to be delivered in the form of video recordings which were less effective than campus-based hands-on learning.

5.2 Timetabling

The new curriculum made timetabling easier than for several different but interconnected programmes. However, for in-person teaching there were issues with room capacities when social distancing was required. The number of concurrent sessions required for the large cohort filled the timetable and put a strain on teaching resources. This meant that activities such as laboratories and design classes took place over the entire year, and with lockdown periods switching on and off, this created disappointment for students who did not have the opportunity to undertake the activities.

5.3 Student teamworking

Effective teamworking is an essential skill in engineering and having multiple opportunities for students to practice this in their first year was key to the curriculum design. It was planned that teamwork would form the main teaching and learning environment for the 'Engineering by Investigation' and 'Engineering by Design' units.

So, during lockdown this was implemented by online group-working tools such as Blackboard Collaborate and MS Teams. However, many students struggled to form effective teams in this way, particularly if they had never met in person, and this appeared particularly acute for first years. There was a general reluctance to engage in public online activity which resulted in some disengagement from the group activities. Whilst this was not unique to this programme, having group-working central to the curriculum has proved particularly challenging for remote and hybrid learners. It became clear that the degree of support that students receive in person from each other is critical to their ability to work in teams.

6 DISCUSSION

In this study several features of a new Engineering first year curriculum implemented at the University of Bristol have been discussed. Evaluation is ongoing and proper results will only be available at the end of the summer, but initial indications are positive.

Some of the positive features have been illuminated by the harsh light of the pandemic, but would they have been suitable in all adverse situations? To answer this it might be useful to see if the features fit with the essential qualities of resilience such 'slack', 'requisite variety' and 'decoupling' proposed by Pinheiro and Chow et al [5,6]. The concept of slack – a buffer of redundancies and resources – could be said to be promoted by team teaching, teaching delivery methods such as the flipped classroom and the use of mixed sources/online sources, and by programmatic assessment. However, in recent years, a drive towards efficiency and strategic management in Universities runs contrary to the accumulation of sufficient buffers and resources to be capable of handling any situation. Partly because of this, during the pandemic, staff and resources have been stretched to their limits. Requisite variety is promoted again by teaching delivery methods, but also by skills teaching and interdisciplinarity. It is important to ensure that this diversity of staff, methods and approaches continues forward into the future. The loose coupling of entities within the system is encouraged by the autonomy and independence of academic staff generally in the Universities in the UK and this was a considerable challenge to reconcile in the process of curriculum review. However, from this very autonomy allows agility and flexibility of action in a crisis. Generating staff commitment to the year as a whole is essential for generating resilience.

Chow et al.'s suggested qualities of adaptability, creativity, connectivity, diversity and endurance were also embodied by some of these features. Adaptability was promoted by the simple structure, the focus on programmatic outcomes, programmatic assessment. Creativity was promoted by the focus on learning outcomes, thus allowing staff to be more creative in their ideas. Interdisciplinarity also led to creativity, as did team teaching, as staff worked across disciplines to develop ideas together. Connectivity and sharing of resources happened across the departments allowing best practice to flourish and diversity of approaches to be catered for. Diversity often means different viewpoints and it took considerable tact and goodwill to ensure that all voices

were heard to move forwards together. Endurance was a quality much needed by staff and students throughout the pilot year and reducing the emphasis on summative assessment gave a little more space to develop this, rather than the usual relentless schedule of coursework and exams.

It would be useful to reflect on how well this or any curriculum can flex to all the possible effects of adversity. The COVID-19 pandemic has caused all but two possible adverse effects to higher education mentioned in the introduction and Universities have adapted accordingly, demonstrating their resilience as institutions; but there are elements of this new curriculum which the first-year curriculum team have struggled with, including managing laboratory closures (despite some exceptionally innovative workaround solutions), the high level of student teamworking required for the new curriculum and its timetabling. These elements will be the focus of efforts next year, as it is important to note that this curriculum review is in its pilot year. The next section will discuss the next steps and the final implementation of this curriculum review project.

7 NEXT STEPS

The new combined first year will be fully implemented in September 2021. The curriculum implemented in September 2020 will be further consolidated and adapted over the next academic year: there will be a single engineering science unit with the introduction of more electrical engineering and more complementary sequencing of subject matter. Computing will be combined with experimental practice, which reflects practice in industry and the disciplinary unit for each programme will be strengthened. The year will be extended to include the new Bristol Electrical and Mechanical Engineering degree course.

There will be further movement from summative to formative assessment and pass/ fail summative assessments. Overall, these further developments are moving towards thinking about the learning outcomes of a programme as a whole and focusing students' efforts on meeting those. This builds resilience both in the delivery of the programme and in students' study, where the connections between the units should hopefully become clearer. The increase in formative assessment and the online nature of the teaching means that it may be possible to find out more easily where and when students are having difficulty. The emphasis of the first-year assessment will be on the skills that they need to display to be successful for the remainder of their degrees.

After the first year, the students follow disciplinary programmes. The changes engendered by the new first year have caused change to the curriculum in later years. The overall aim is that all students will have a good grounding in the basic academic and professional skills required and will have developed effective and healthy study methods by the beginning of the second year.

8 CONCLUSIONS

In this work, the features of a new engineering first year curriculum have been examined in terms of resilience and lack of resilience. A simple and standardised structure, an emphasis on skills-based learning and interdisciplinarity, more programmatic and less summative assessment, team-teaching and best practice pedagogy have all played their part in making this curriculum suitable to be rolled out a year early. Aspects that have been problematic have included the dependence on laboratories, timetabling limitations, and student teamworking. The next steps in the implementation of the curriculum have been discussed. This crisis has offered an opportunity to look at features of curricula that may make them more resilient. It is hoped that this work offers ideas to others who wish to embed resilience into their curricula.

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