REMOLDING THE UK STEM GRADUATE FOR 2020
The Collaborative Teaching Laboratory

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INTRODUCTION

The Engineering UK report 2016 forecasted that its economy will require 1.82 million people with STEM skills by 2022 [1]. To meet this challenge and to forge a new calibre of STEM graduate, the University of Birmingham is embarking on a £40M flagship STEM Collaborative Teaching Laboratory (CTL). Due to open in 2018, it will provide contemporary and centralised laboratory facilities for several disciplines – Mechanical Engineering, Civil Engineering, Electrical Engineering, Computer Science, Metallurgy and Materials Engineering, Chemical Engineering, Chemistry, Bioscience, Environmental Science and Maths.

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Integral to the CTL's vision will be its transformational teaching by delivering an enhanced student experience. This will be through a practical and professional skills-based curriculum that is interdisciplinary, collaborative, inclusive, student-owned and enquiry-based. In this paper we report on the plans for the CTL which are the outcome of several studies and workshops held between 2014 and 2016 with the CTL stakeholders, alumni sponsors, STEM faculty, industrial partners, potential suppliers, and students. The outcome from these exercises in these workshops is summarized in this paper: a contemporary learning space, a set of curriculum development goals, technologies and skill sets, and a collaborative pedagogy. By combining learning space redesign with curriculum development, we aim to elicit and develop far-reaching curriculum change across scores of different undergraduate labs, which will benefit thousands of undergraduate students over the next decade.

1 THE BUILDING

The building (*Fig. 1*) is designed with significant input from all stakeholder groups - estates, hospitality, academics, professional services staff, and students. It comprises of three floors. Each floor houses a formal learning lab. The architectural concept is to keep these laboratories distinct to retain disciplinary identity. Their spaces are shifted in the horizontal plane, and the resulting space created between them enclosed. This space, which links the laboratories together, becomes an informal learning space ("glue") and it is the largest space in the building, designed to be accessible and to accommodate over 500 students.

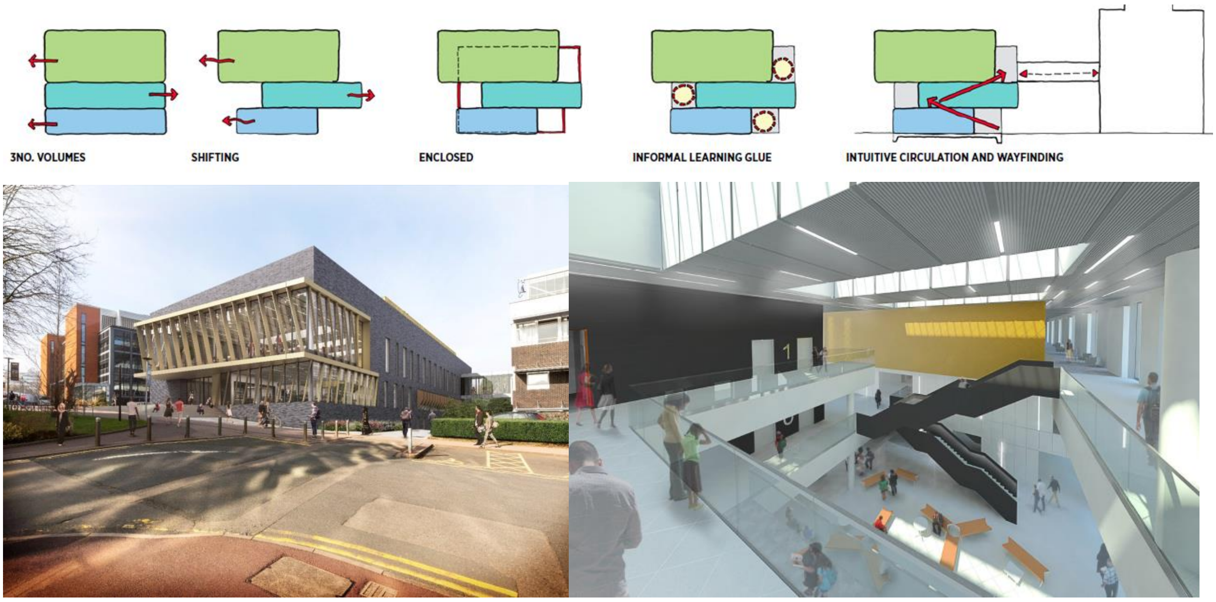

Fig 1: CTL building plans. The functional concept (top); external render showing main entrance (bottom-left); internal render showing the discovery lab and informal learning zone (bottom-right)

This configuration of the CTL's learning space is optimised to simultaneously promote strong disciplinary-focussed teaching, yet facilitate true collaborative and interdisciplinary learning, without weakening the individual disciplines' identities. For teaching of biosciences, chemistry and chemical engineering, the ~900m^2 Wet Lab contains fume cupboard spaces and open bench spaces. It can accommodate groups of up to 200 students supporting parallel sub-groups of 20 on different topics. The open bench space supports a range of locally stored equipment which can be swapped easily. For teaching civil, electrical and mechanical engineering, the

~500m^2 Dry Lab provides flexible bench space for groups of up to 176 students. Like the Wet Lab, equipment and teaching materials are stored locally for interchange. Notably, there are audio-visual facilities for all students to assist in video capture of activities for assessment. For teaching of computer-based activities such as simulation and modelling, all disciplines are served by a ~700m^2 E Lab. This provides computing facilities for 200 students with portioning and acoustic design to support mixtures of formal and informal learning activities, including lectures and small group teaching.

For interdisciplinary and collaborative-focussed teaching, there is the ground-floor ~100m^2 Discovery Lab. This will support a variety of teaching and learning modes required for modern engineering curricula to complement the bench-based E lab, Wet Lab and Dry Lab. Additionally, an Engineering Lab in an adjacent building provides further on-bench workspaces. While these formal labs' foci is reinforcement of disciplinary knowledge and bench-based design/implementation, the Discovery Lab will focus on reinforcement, supporting projects requiring knowledge discovery, real-time distance collaboration, and off-bench group activities. It will also host extracurricular activities around community building, such as student clubs and outreach.

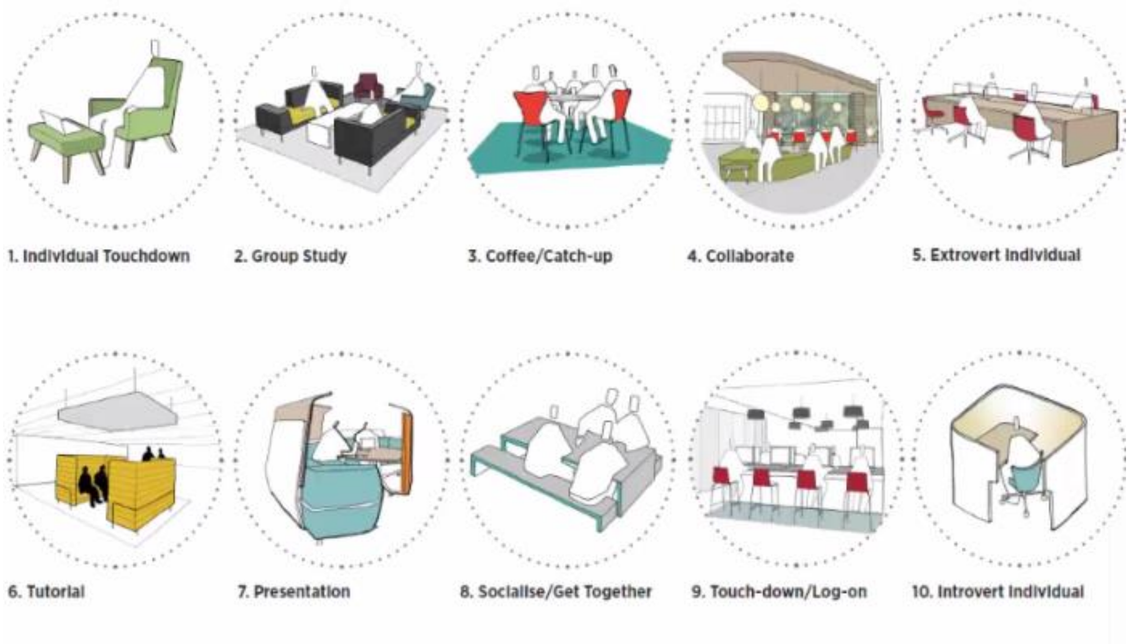

Fig 2: The 10 distinct informal learning modes identified by studying existing open learning spaces on campus and designed into the CTL informal learning zone.

The Discovery Lab and its links between labs – a 300m^2 informal learning space - support students in a variety of different modes of self and group study, afforded by careful consideration of furniture, fixtures and equipment. In designing this space, student activity was assessed across campus in existing learning spaces. Ten distinctive modes of study were identified (*Fig 2*). These are "Individual Touchdown" for short low-effort computer-based activities; "Group Study" for structured activities; "Catch-Up" for e.g. socialising over a beverage; "Collaborate" for group activities around shared artefacts such as whiteboards; "Extrovert Individual" for individual study in the presence of others; "Tutorial" for academic and student interactions; "Presentation" for group work requiring access to visual aids and audio-visual equipment; "Get Together" for general socialising; "Touch-down/Log-on" for desktop-based low-effort activities, and "Introvert Individual" for individual study in solitude.

Achieving the right mix of these modes to satisfy student demand requires a flexible configuration adaptable to a mixture of these modes throughout the day and academic year.

2 ENGAGEMENT WITH INDUSTRY

Industrial stakeholders and sponsors have engaged with the CTL through several workshops held since 2014. Given a set of structured questions posed they provided ideas and guidance on how the STEM graduate needs to change. In this section, notable themes that emerged from these sessions are discussed.

On the question of inspiring more young people to study STEM subjects, employers recommended greater focus on highlighting the relevance of undergraduate skills to the workplace and society. To widen diversity by attracting more females, stronger links with the social side of engineering were encouraged. The importance of bursary schemes was identified.

There was additional help identified that industry could bring to the teaching of the STEM subjects. While work experience placements, either over vacation or for a whole year were well established, there was a demand for more short term exposures such as open days and `boot camps' to be embedded into the undergraduate curriculum, hosted both in the CTL and within companies.

3 CURRICULUM DEVELOPMENT GOALS

The CTL signifies a key shift in the culture of STEM education at the University; a multidisciplinary engineering focus [2] on student-driven curricula that first and foremost equips graduates with a portfolio of their experience at university which demonstrates their learning, skills and capacity to potential employers. This is given equal priority to achieving a degree which satisfies the accreditation requirements of the professional bodies for each discipline. To achieve this, digital delivery and capture of laboratory work is desirable, and is affected by several curriculum development goals which have been negotiated and agreed with students, staff and employers.

The first goal established is to enhance student understanding and lab skills by facilitating the introduction of pre-lab activities into the curriculum. These include pre-lab activities include remote simulation, pre-lab technique development, and equipment familiarisation [3]. The introduction of these pre-lab activities will ensure that student's time within formal laboratories is maximised with respect to the learning outcomes. Activities which can be conducted prior to the session such as health and safety training and aspects possible by simulation are delivered digitally prior to sessions, and include assessment components to ensure that students have reached the requisite level in order to conduct the lab. Auto-grading and auto-generated feedback are employed. These will complement (and not replace) individual feedback.

The next goal concerns graduate skills. Students will be equipped with the appropriate skills and knowledge to work in modern research industries and organisations. This includes employing cutting-edge knowledge, techniques and methodologies informed from close industrial liaison. The skills that graduates require are considered from three perspectives: the technician-oriented skills that industry requires for entry-level graduate jobs, general laboratory skills around scientific enquiry and engineering design, and interdisciplinary/collaboration skills. These are considered as part of the collaborative pedagogy which is described in section 4. Finally, broader skill sets are refreshed into undergraduate programmes across all the academic schools. This includes the “soft skills” requested by industry; the ability to work successfully as part of an (interdisciplinary) team, which includes an understanding and appreciation of the role of other disciplines in the problem solving process, an awareness of diversity considerations within the teamwork process, the ability to (project) manage tasks to achieve a successful conclusion, managing conflict and conflict-resolution, leadership/followership and resilience.

To fulfil all of these goals, curricula must be changed across all the academic schools. The curriculum development activities must embrace new educational technologies as and when they become available, notably the increased use of digital devices, learning analytics and adaptive personalised learning, augmented and virtual reality, makerspaces, robotics and the internet of things [4]. These technologies and the CTLs redesigned learning space and modes of informal learning will afford new pedagogies such as empowering learners through “co-creation”, transformative approaches that promote agency and competence beyond knowledge and understanding, interdisciplinary learning and collaboration, and social learning through informal and co-curricular opportunities [5]. To this end, we have developed a collaborative pedagogy which is described in the penultimate section.

4 COLLABORATION PEDAGOGY

To enhance the existing research-led skills provided, there has been an increase in promoting interdisciplinary engineering education which links learning outcomes to professional practice rather than technical knowledge e.g. Conceive Design Implement Operate (CDIO) lifecycle [6]. In parallel, education research is developing a powerful framework for modelling interdisciplinary thinking [7]. We use these two strands to develop pedagogy for collaboration across all academic schools.

By nature, STEM professionals in industry and research often embark on collaborative endeavours requiring an integrative approach between disciplines; information and ideas are frequently exchanged [8]. The nature of the integrative collaboration can be distinguished as either multidisciplinary or interdisciplinary [9]. In a multidisciplinary collaboration, practioners work together on common problems, but their discipline and identity remains intact. It could be argued that in industry this is a default mode of collaboration based on the need for efficient division of labour to produce timely solutions. However, interdisciplinary collaboration requires an investment in effort to understand how one discipline fits with others, the desired result being that one’s own discipline is strengthened and extended. The CTL will therefore provide a valuable space to conduct interdisciplinary collaborations by undergraduates who are later, as graduates, capitalised by industry in more multidisciplinary “division of labour” conditions.

Multidisciplinary working is frequently observed in engineering education if learning outcomes do not address “interdisciplinary thinking”. This can be observed in many group engineering projects, where students will divide the work into different systems e.g. in electrical engineering subsystems for power, communications, and interface. The outcomes are typically a working solution and a “group report” which aggregates and integrates individual contributions; group dynamics are often considered via a reflective exercise or commentary, but the interdisciplinary thinking skills which inform this reflection are seldom made explicit. Furthermore, it is suggested that engineers and scientists resist interdisciplinary working due to their reliance on strong consensus built on agreed standards and quantified rigour, which risks rejection of disciplines that thrive on controversy such as social sciences [9].

Definitions of interdisciplinary thinking and pedagogy generally occur in the social sciences and not STEM subjects; e.g. this definition is at the forefront of understanding the concept: “a Set of skills for Collaboration with Subject Expertise requiring Communicating across expert languages; Transferring/Integrating conceptual knowledge; Negotiating epistemological barriers and Recognising limits of expertise/disciplinary ownership” [10]. However when we conducted workshops on collaboration with STEM academics and presented such definitions, we received several criticisms from participants regarding the use of “social sciences terminology”, underscoring how collaboration can be resisted even by those engaged. Interdisciplinary thinking skills need to be made relevant to STEM subjects and stated in terms easily understood.

The curriculum development strategy in the CTL makes collaboration explicit. Learning outcomes with interdisciplinary elements have parity alongside learning outcomes that require collaborators to produce an engineering output (i.e. a product, process or solution). We draw on the social sciences for interdisciplinary thinking pedagogy to elicit a collaborative skill set which will develop engineering graduates with a 21st century “cognitive flexibility”. This is made relevant to a STEM audience by toning down the social sciences language, and relating it to lifecycle views of engineering curricula. We use CDIO for the lifecycle model; a popular approach to engineering curricula that defines a set of teaching standards and relates them to a four stage engineering lifecycle process.

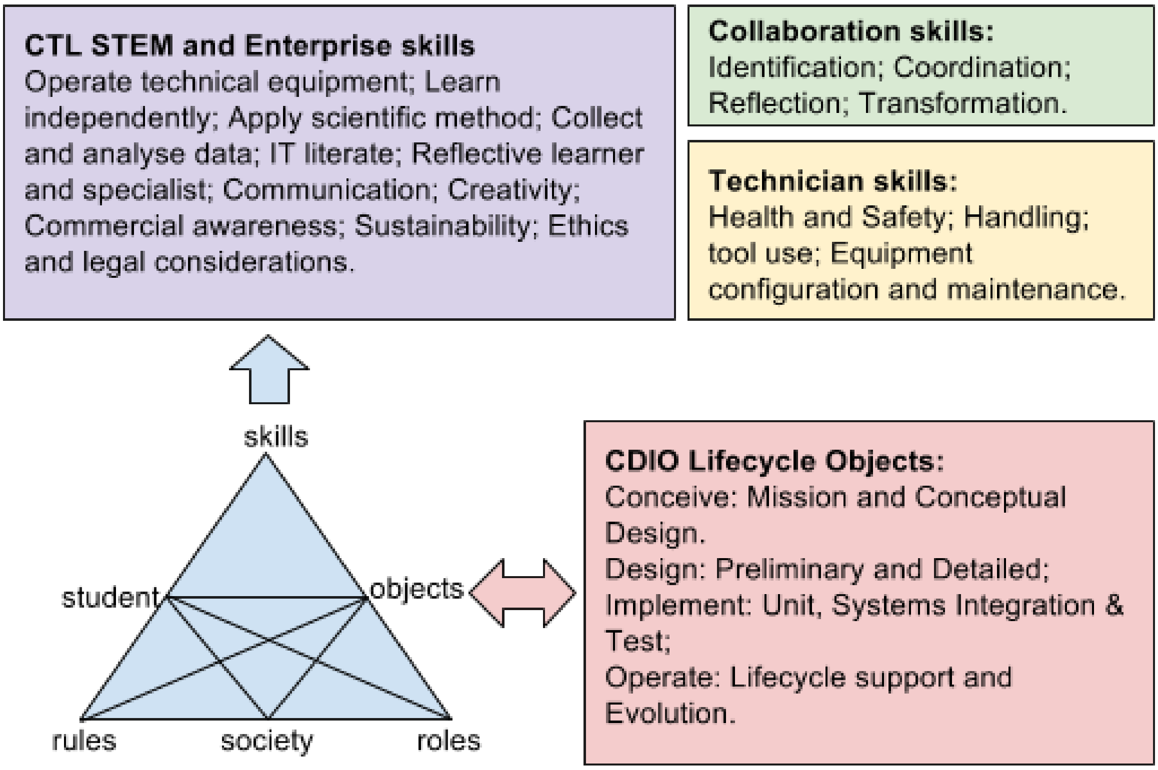

Fig 3: The CTL Collaboration pedagogy. A students discipline is modelled by an activity network. Learning outcomes are demonstration of the 3 skill types around boundary objects defined as CDIO lifecycle objects.

The resulting collaborative pedagogy is shown in *Fig 3*. Collaboration skills are made explicit and distinct from STEM, Enterprise and technician skills. Their demonstration forms the learning outcomes.

The student's discipline (e.g. a chemical engineering student) is considered as an Activity Network (the triangle in *Fig 3).* An Activity network is a multi-factored model of a system, which consists of interactions between the person, their tools/methods, rules, community and the division of labour. When considering the transfer of knowledge and concepts between one student and another, there is collaboration between two activity systems about a "boundary object" via "boundary crossing skills" [11,12]. There are four mechanisms proposed for learning at this boundary - identification; coordination; reflection and transformation. Each containing several characteristic processes [13]. To this pedagogical model of collaboration we consider boundary objects as the activities and engineering lifecycle tasks defined by CDIO [6].

Multiple factors serve to motivate student collaboration across STEM disciplines. E.g., there can be strong student motivation to future proof their skills, widen their perspectives, increase their competitiveness and apply their knowledge. However these are countered by distractions from disciplinary focus, perceptions of superficiality and learning stress [14]. By introducing a rigour to what is meant by "interdisciplinary thinking" through this collaborative pedagogy, we aim to reduce these discouragements.

5 SUMMARY

The benefits of the CTL to industry were underscored by its rigorous approach to collaboration. Industrial project managers and engineers could bring live problems and projects and work with students to come up with innovative ideas. This will help students understand how ideas can translate in the wider context of a company vision/project requirement, and help industry to harness young people to challenge traditional thinking and ideas. In effect, while the core CTL function is running undergraduate lab sessions, it will simultaneously operate as a business/networking providing facilities/access for smaller companies to develop products, services and solutions.

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