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Progressive development of professional engineering skills through programmed project activities in EE.

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***Abstract*—This paper presents a model for the progressive development of product development skills through programmed project activities across Undergraduate programmes in Electrical or Information Engineering. The model is based on a substantial project in each year of the degree programme and that the project is technical in nature. Other than these two requirements the proposed model can be applied. The model shows how the generic CDIO (Conceive, Design, Implement, Operate) has been applied across a set of 3- and 4-year Engineering degree programmes to derive a set of staged learning objectives that build competence and confidence in a range of important engineering skills. Some of the skills developed are Needs analysis, requirements capture and specification writing; Creativity and innovation; Design (in the broadest sense); Modelling and simulation; Manufacturing; Assembly and testing; Cost and market evaluation; specifications for use; product usage and life cycle awareness; and professional record keeping and reporting. The main challenge in creating and implementing this plan was to ensure a minimum number of teaching hours that had to be devoted to these perceived as not 'real engineering' content.**

The model has only be running for two year so judgements on its effectiveness can only be preliminary. However, a full first year of student project work has been marked so early commentary on the development of the model and its overall efficacy can be discussed.

The paper will set the scene for the overall design of the model and give a description of it. It will then discuss comments from the markers of the stage 1 and 2 project reports on the effectiveness of the projects so far and of adjustments that have been made to make them more effective in achieving the joint objectives of developing students' technical abilities in engineering and the skills expected of a professional engineer.

***Index Terms*—component, formatting, style, styling, insert**

I. Introduction

The skills engineering graduates should possess has been explored through surveys, job advert analysis and by recruitment agencies and articulated through specifications and benchmark statements.

Surveys are carried out periodically by the UK Government, the latest being 2019 [1]; by Professional Bodies, the most recent IET survey was reported in 2019 [2]; by consultancies, such as the McKinsey 2020 report [3] and by funded projects specifically designed to explore sector skills gaps, an example being the EIE-Surveyor project [4]. Job advert analysis gives a restricted but different insight into skills required by recruiting companies [5], [6] while individual, larger sized recruiter companies also list skills required for a range of careers and specific vacancies, examples being indeed [7] and target jobs [8].

The UK Professional Engineering Competence and Commitment (UK-SPEC) states the graduate requirements for UK engineering programmes at the different accreditation levels. There are 5 "broad areas of competence and commitment": Knowledge and Understanding; Design, Development and solving engineering problems; Responsibility, management and leadership; Communication and interpersonal skills; and Professional commitment [1]. In the US it is ABET, the Accreditation Board for Engineering and Technology, and the Engineering Accreditation Commission that define their standard for engineering graduates [9]. Whichever accreditation system is used, the need to meet Professional Body Accreditation requirements is paramount in most countries.

All of these routes to guidance on the content of new programmes have an important point in common, they all stress the need for development of competence in non-technical areas alongside the technical content. The non-technical areas are the personal and professional skills and in aspects of business relevant to the programme subject. The personal and professional skills are variously terms generic or transferable skills and include problem solving, teamworking, personal time management, research skills and many more. For a subject such as engineering it is necessary to carefully align each programme to these requirements [10].

A different way of considering the syllabus that looks holistically at programmes is the Conceiving — Designing — Implementing — Operating, the CDIO model, way of thinking about products, services and processes. The CDIO Initiative was started in October 2000 by a consortium comprising MIT[1], and Chalmers University of Technology, Royal Institute of Technology and Linkoping University[2] [11]. The aspiration of the consortium was to "improve undergraduate engineering education in their countries and, eventually, worldwide." It is an open-architecture designed to allow undergraduate engineering programmes to be configured to specific subjects or needs. The CDIO syllabus identifies a whole set of skills

[1]USA
[2]Sweden

appropriate to Conceiving, Designing, Implementing and Operating systems “in the enterprise and societal context” which sit alongside Technical knowledge; Personal and Professional skills and attributes; and Interpersonal skills [12].

There is no conflict between the CDIO syllabus and the National standards their considered (USA, Canada, Sweden & UK), in their study to demonstrate this. Perry et al. [13] added that they “argued that the CDIO Syllabus is aspirational and, as such, it complements the threshold requirements of national accreditation criteria”. By some the CDIO syllabus is seen as the one to follow for a successful ABET accreditation [14]. The appropriateness of the model to the electrical and electronic engineering [15] and Information Systems have also been demonstrated [16]. In this paper the CDIO model has been used as a basis for specifically structuring the way skills develop across the study years and is presented in the form of “stories”.

II. Programme Design Methodology and Structure

A suite of 8 programmes have been designed comprising 4 technical ‘themes’ each with a 3-year BEng and a 4-year Integrated Masters MEng version. The ‘themes’ are ‘General Engineering’, ‘Medical Engineering’, ‘Robotic Engineering’ and ‘Micromechanical Engineering’. All programmes have the same basic core content with additional themed core and optional technical modules to flavour the programme. The ‘General Engineering’ theme being the route students can take through the range of modules that gives them maximum module choice. The generic structure has projects built into each year starting at 20 UKCU (UK Credit Units, equivalent to 10 ECTS), 30 UKCU in study year 2, 40 in year 3 and 80 in year 4. All projects are group projects except the graduating year project, which is a singleton project.

All projects are design to give students experience in one of the ‘themes’ with the first-year project being in the medical area, the second in robotics and the third having significant micromechanical elements. All projects are supported by lectures, briefings and supporting learning resources.

The programmes were designed using “stories”, very like user case stories in programming. The first was the technical story. This addressed the analogue, digital electronics, programming, materials, mechanics and fabrication content. The technical objectives of each project were established to align with the content of the technical modules in each year and to the broad expectations of the level expected of degree level achievement. The technical story showed the growth in technical expectations over the years.

The second story was the project story. This included a detailed description of the projects and where the technical emphasis was. The project story aligned with the technical story and the labs associated with the technical modules to ensure students were equipped with sufficient knowledge and understanding to complete their tasks. This is not to imply all teaching is ‘teach first experiment second’. The stories allowed for a flipped classroom pedagogy and, where this was employed, provided information about the necessary scaffolding required.

TABLE I
Development of Project Deliverables

Year 1	• Record of their client meeting(s). • Device functional specification. • Device user operational guide. • All test results. • Ethical compliance statement. • Initial project presentation. • Project specification.
Year 2	• Record of component, subsystem and product testing together with compliance against given communication protocol. • System functional specification. • User operating manual. • System EMC and Health & Safety statement. • Ethical compliance statement.
Year 3	• System functional specification. • Final system verification against requirement specification. • Record of all group meetings. • User specification. • User manual. • Fully costed Business Plan. • Full Bill of Materials. • Manufacturing documentation pack. • Operational environmental and end of life specification. • Ethical compliance statement.

TABLE II
Incorporated elements of CDIO

C: Conceive	• Specification: Needs analysis, requirements capture & product specification • Innovation
D: Design	• Design • Modelling and Simulation
I: Implement	• Manufacture • Manufacturing limitations • Assembly and Test • Cost and market evaluation
O: Operate	• Specifications for use • Product Usage & Life Cycle

The project story builds competence through a deliverables framework and used the CDIO model to show how technical and project management complexity develops through the study years. Table I shows the project deliverables across the three group projects.

Table II shows the elements of the CDIO model that are incorporated into the project story. A table of element against project year with a description of student support and what they are expected to demonstrate in each cell. Table III shows the detail of the “Needs analysis, requirements capture & product specification” component of the Conceive element and how this is developed across the projects. It also shows what support students are given and what is expected of them. This is replicated for all components of all 4 CDIO elements. The complete table gives a detailed description of the support resources needed, including student briefings required for the ‘story’.

The final story is the graduate and professional skills story. This includes how laboratory practice skills, awareness and compliance with health and safety in laboratories requirements and the more generic transferable skills are developed in each

TABLE III
DEVELOPMENT OF THE "NEEDS ANALYSIS, REQUIREMENTS CAPTURE AND PRODUCT SPECIFICATION" COMPONENT OF THE CONCEIVE ELEMENT

Year 1	Students will be given a general overview of the project and briefed that they need to discuss with the client the application area and actual specification for their project. They will be given guidance on what a product specification should look like and that it should be able to be tested to verify the solution they come up with meets the specification. They should be given guidance on the basics of client meeting etiquette.
Year 2	Students will be given a general overview of the project and briefed that they need to discuss with the client, analyse the identified need and produce the actual specification for their project. Students will be required to define what they will deliver to the client and will be assessed on their ability to deliver.
Year 3	Students will be given the broad topic within which they will be required to propose a product that fits the general requirement of being a complex system with a number of different interconnected system components. The group will be responsible for creating the user specification based on a needs analysis and presenting this to their client as a potential solution. They will then discuss with the client the actual specification for their project with all appropriate parameters specified with tolerances. They will be given guidance on what a detailed/professional product specification should look like and that it should be able to be tested to verify the solution they come up with meets the specification. Students will be required to define what they will deliver to the client and will be assessed on their ability to deliver.

TABLE IV
COMPONENTS IN THE PROFESSIONAL AND GENERIC SKILLS AREAS

Professional skills	• Laboratory Practice • Health and Safety
Generic / Transferable skills	• Group Working • Research • Communication • Ethics • Project Management • Meetings & Meetings management • Risk Management • Time Management • Data Security

year. Tables of skill and how it is developed in each year have also been developed. The components are shown in Table IV. The term 'component' is used because not all of them are strictly classifiable as skills.

Finally, learning outcomes appropriate for each year were written to align with the assessment plan for the overall programmes.

III. MODEL IMPLEMENTATION

The structure of the model is based on a project in each year with progressive stages to build competence through deliverable framework and used the CDIO model. The project is considered as a central point for each year, where the theoretical knowledge from lectures in other modules is fed into practice. This requires a stringent coordination of other modules to deliver required subject knowledge for implementation into the project. This gives an opportunity to students to experience study theories into practice within a structure of analysis, creativity and innovation, design and manufacturing, modelling and simulation, assembly and testing, cost and marketing.

IV. RESULTS AND DISCUSSION

As is noted above, delivery of these new programmes is currently in the second year so we have a full year's year 1 results and feedback; and a near complete year 2. The first delivery was a 'covid' year and was delivered with no conventional lab or face to face project time. Home kits of parts were sent to all students so they could complete a group project with each student completing practical work. Teaching staff said "*Students in general prefer in person labs but the take-home robot kits were very popular and many students did better than usual with them.*" and "*Students got engaged well with home kits.*" The cost of creating individual kits was significant and not affordable over the normal practice of one kit per group. We are now in the second and more conventional delivery of the first and second years.

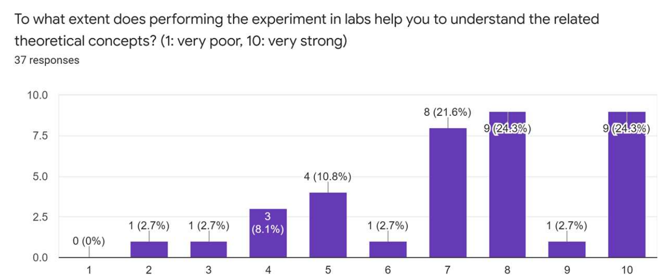

Fig. 1. Perceived value in experimental work.

A survey of students shows that last year approximately 2/3rds of students enjoy practical work more than lectures and, as shown in Fig. 1, students understand the extent to which performing lab experiments helps them understand the related theoretical concepts. However, there was a preference for small group (1-3) rather than the planned 5-6 student size. There was also greater than 50% preference for detailed instructions and more structure rather than an open-ended project brief and a near 75% preference for regular, intermediate targets rather than the originally planned termly (10-week duration) targets. Overall, feedback shows that using projects as a significant component is being well received by the students however they prefer a more structured and shorter duration activities. This aligns with the more prescriptive approach taken in Schools and suggests a gentler transition from a carefully scaffolded and managed first year would be ease this study culture shock. All students in each group completed a team role inventory and shared their team role preference as a first step in understanding team effectiveness. One student commented "*I would prefer that we were given smaller projects with different groups each time. This way we learn more about group dynamics etc rather than simply being in a group and not changing or learning much more about teamwork.*". The results suggest that one single large project gives limited scope for students develop their team working skills. Additionally one student said "*Attendance should be looked at more closely, some members of the team attend less than half of the sessions in a term.*" Another student said " *It is also the case that with a large project tackled in a large group, some individuals do not contribute effectively* ". This supports the academic lead who has observed an uneven contribution by team members. Aside from the inequity of effort, the main concern here is that some students will not be able to demonstrate all the planned learning outcomes. Providing more structure and dividing the groups into pairs for shorter term more prescribed activities will correct these problems.

Students are also challenged in breaking the work down. Whilst this is not specifically an outcome in the way the CDIO component skills development has been structured, it is a useful observation as far as managing our expectations of what the students can achieved in their first year. Developing the skill of breaking work down into WBS for a large project is clearly a later year learning goal.

An unexpected observation is that students feel overwhelmed by the work they are expected to do. This could be attributed to the open ended nature of the project but since this significantly affects student motivation, it is feedback we need to use. The large number of elements and component skills in the CDIO model has the potential of creating a very large number of learning outcomes. Whilst this would raise the visibility of what we are trying to do, it is likely to increase the perception of the amount of work. Instead, discussions have turned to embedding the requirements into the formative and summative assessments. Doing this will test whether the learning outcomes are demonstrated and show the students that they really do matter.

Outcomes presented here are based on overall observations acheived so from from implementation of this model, which has only been running for two years. Further measurements on the evolution of the grades by students through the progressive development of this model necessitates more analysis and studies after completion of the program by the first cohort.

V. Conclusion

The primary objective of this paper is to introduce a different way of thinking about the design of new Engineering programmes – through using the CDIO model and documenting the progressive development of personal and professional skills through 'stories'. Results of the first two years of actually running programmes developed using this approach, even with covid as a complexity, have provided useful information about how the model can be adjusted to be more successful in the future. The specific adjustments being to retain larger group projects but to be actively managing them at the activity level so pairs of students know what they are required to do to complete short duration targets that build to the overall project. The other valuable lesson learned is in practically how a large number of learning outcomes can be measured without causing students feelings of being overwhelmed and demotivated.

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