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DIGITAL TECHNOLOGY IN ENGINEERING DESIGN TEACHING

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ABSTRACT
Digital technology is widely used in engineering design teaching, enabling students to create parametric models of their solutions and data files for computer-aided manufacture (CAM). However, the digital industry is predicted to grow significantly throughout the decade and, in particular, digital twin applications. This paper compares the digital environment in engineering design teaching at two universities in terms of how their design teaching uses digital methods. The design projects and units in which digital technology is taught are identified and compared to give a broader understanding of the benefits and challenges to the teaching delivery. The different levels of technology in the digital environment are mapped against the academic years to understand the teaching strategy for large cohorts of students.
At both universities, design teaching uses drawing practice to build the fundamentals of CAD modelling and give students the opportunity to manufacture their own designs by using digital technology to produce CAM data files. Both universities deal with large cohorts and have adopted different strategies for dealing with the inherit challenges this brings. The delivery of digital simulation is shown to be similar, but contrasts at the digital twin level, where significant resource is committed.

Keywords: Digital technology, engineering design, undergraduate

1 INTRODUCTION
Digital technology is an essential part of design teaching as it enables students to create parametric models of their designs and data files for computer-aided manufacture. The adoption of such technology in engineering is expanding from the increased availability of 3D printers in workshops and at the personal level. On the global level, the digital industry is predicted to grow considerably, supported perhaps by confidence from the use of technologies throughout Covid-19 pandemic. An advanced approach within the industry is a digital twin. A digital twin is a virtual copy of a physical object connected by data transfer between the two. An important use of a digital twin is that it can provide information on how the real-world changes over time, but to be a digital twin the model must be associated with an actual physical object [1]. From 2022 to 2029, the global digital twin market is predicted to grow from nearly 9 billion to 96 billion USD [2].
The focus here is on the design teaching in undergraduate mechanical engineering courses at two universities, the University of the West of England (UWE) and the University of Bath. It is on the extent to which they include digital technologies when teaching engineering design. Equipping students with digital technology skills is valuable for industry and the placement year, but as cohorts are now over three hundred, careful planning and resource are required to ensure the teaching delivery is effective. To assist in appraising how the different types of digital technology are learned, they are considered within a digital environment comprising digital technology, digital simulation and digital twin. Digital technology is essentially a standalone programme which gives some form of output, such as, a CAD model of a design. Digital simulation explains how that design responds to set inputs, and a digital twin is as above.

2 DESIGN TEACHING

This section describes the design teaching at the University of Bath and UWE.

2.1 University of Bath

In the Department of Mechanical Engineering at Bath, the course structure comprises a four-year MEng, in which there are five programmes (mechanical, aerospace, automotive, design and manufacturing). All programmes are taught together in the first two years, followed by compulsory and chosen options in years three and four, respectively, that adapt the curriculum to suit the programme. Students may choose an industrial placement year after the second year.

This section describes only the design teaching common to all undergraduates which occurs in the first two years. The five programmes are taught together as one cohort, which gives the benefit of all students receiving the same delivery but presents resource challenges for a class size now of over three hundred.

Table 1. Structure of design units at Bath

	S1	S2
Y1	Design 1 2D/ 3D CAD (I)	Design 2 CAD (I), CAD(G) BoM
Y2	Design 3 CAM data files, numerical model	Design 4 CAD(G)
Y3		GBDP CAD(G) FEA(G) CFD(G)

In the first semester of year 1, drawing practice is taught through both hand drawing and CAD. Here the learning and assessment is on an individual basis, denoted by (I) in table 1. Students take their first step into design in the following semester in a constrained exercise and an open exercise. In the open exercise, students work in small groups and use parametric software to now share and co-develop parts and assemblies, denoted by CAD(G). In this group activity, design runs from concept to making and assembling a prototype. This exercise is set up as a "novelty" design to enable groups to create a range of concepts [3]. To facilitate the make, students use digital technologies to create CAM data files for computer-aided manufacture of their bespoke 2D and 3D CAD parts. In the second year, students simulate how stress is distributed across a structural part in a sub-assembly. The simulation is created by stress calculations and is a virtual digital technology. Further experience of CAD(G) is acquired in the Design 4 unit, but this time it is in a design of a production machine and factory layout. In the second semester of Year 3, all students study full-time on a group design and business project (GBDP). There are a range of projects from university-based competition projects, such as, Formula Student, to industrially sponsored projects. This full-time, semester-long unit enables the groups to create solutions with parametric CAD models and perform analysis and simulation, where appropriate, using FEA and or CFD.

2.2 UWE

This section considers Years 1 and 2 at UWE in the School of Engineering. For mechanical, automotive, and manufacturing students, design is both a vertical and horizontal thread across the first two years of their BEng degrees.

From a vertical perspective:

Within a year-long, first-year Engineering Practice module, students are introduced to three design methodologies of Double Diamond [4], Stanford Design Thinking [5] and IDEO: Human Centred Design [6]. It is demonstrated via case studies how these can be used to produce solutions for the project week activities later in their studies. In the final weeks of the module, students are also taught how to draft and generate 3D models and assemblies within a computer-aided design (CAD) package. Students are assessed using the SolidWorks CWSA certification process for CAD understanding, their application of the design process is undertaken during the project weeks.

When students transition into year two. In their second-year design module, students are required to follow an engineering design process for the development of a machine system. They are introduced to Pugh's, Total design [7], Systematic design [3], and BS7000 processes [8, 9]. The second-year project has an electro-mechanical flavour as the students are required to design mechanical components, such as, power screws, gears, shafts, and cams. They size and select appropriate actuators, required sensing technologies and control systems, generally PLC or microcontroller (system dependant), programmed as required. Students also size and select standard components, bearings, fasteners, couplers etc. The project is also constrained by environmental and sustainability limitations, health and safety, cost, and risk assessment issues. Students are expected to use Matlab [10] to perform any calculations or to create parametric model development. Although there are some electromechanical experiments in the module, the output of this project is a virtual concept. Students are assessed on their design report, Matlab scripts, assembly and manufacturing drawings, and via a presentation to the "client".
Students on the mechanical with manufacturing pathway take an additional unit where they explore the concepts of design for manufacture and assembly. Students are taught a range of DfX approaches, for additive manufacture, rapid changeover for automation, as well as Boothroyd and Dewhurst main methodology [11]. The students employ these methods on an industrial system, or on the Festo and Siemens cyber-physical smart factory [12] on campus aiming for improved manufacturability. The DfX activities are assessed via a technical design report and viva. Independently of these modules, students are taught how to use finite element modelling to analyse and develop structural design and computational fluid dynamics via Ansys workbench [13]. The ability to use FEA as a design tool is assessed via a plate with stringers type problem.
From a horizontal perspective:
The School of Engineering runs two project weeks per academic year, where the mechanical and automotive students are joined by civil, aerospace, robotics, and electronics students to work on an integrated design problem. To date these project weeks have utilised the problems set by Engineers Without Borders [14]. The project weeks are attached to the Engineering Practice units in each year. During these week students are exploring issues of transportation, sanitation, water security and other infrastructure problems found in areas like Northern Australia, India, South Africa, and Scotland. The integrated teams are expected to systematically employ the IDEO: Human Centred Design process [6] while producing their solutions. The outputs at the various stages of this design process form the assessments for the respective module within which they sit. Reporting takes the form of posters and a presentation.

3 DIGITAL ENVIRONMENT

3.1 Digital levels

The need to reflect on digital technologies in teaching is prompted by both the projected growth of digital twins (Fortune Business Insights) and the increase in research activity noted in this area [17]. To help interpret the form of digital environment used in teaching, three categories are used, digital technology, digital simulation and digital twin. An example of a digital technology is the use of software to create a digital file (of how the design is), such as, dwg, dxf, stl, etc. Simulation is a digital file which accepts inputs to show how a part or assembly would react. Different definitions exist for a digital twin. Here, a digital twin is any virtual file that receives data from the physical part or assembly. It must be said that this is a simple interpretation of a digital twin and ignores higher levels of digital-physical feedback and control that are possible [15].

Table 2. Levels of digital teaching

	Design project or unit							
Digital twin	Engineering Experimentation unit				DfMA (BEng in Manufacturing only)			UWE
								Bath
Digital simulation					Systems design unit		Computation methods unit	UWE
					Sub-assembly design			Bath
Digital technology		D&M(I)	Engineering drawing(G)					UWE
		Engineering drawings (I)	Constrained design (I)	D&M (G)		Product design	Machine design (G)	Bath
	Y(0)	**S1**	**S2**		**S3**		**S4**	

3.2 Discussion

Table 2 shows that the design teaching at Bath uses mostly individual digital technologies. A driver for this structure is the layering up of skills as students' progress through the four units and cover the mechanical engineering design curriculum. The teaching focuses on design fundamentals across a range of projects enabling students on all programme's multiple experiences of the design process in a systematic way. The projects give students hands-on experience of using digital technologies in CAD and CADCAM, which also proves to be valuable on the placement year. However, with large class sizes, the open group assignment needs to be planned with technical staff to ensure the manufacture and assembly requirement does not exceed workshop capacity. The scale of the prototype needs to consider the number of parts students are likely to have in the assembly, to budget for the cost of bought-out parts, and to plan for in-university manufactured parts. The technical staff must also prepare orders for bought-out parts and materials acquisition from each group's bill of materials. The additional responsibility for the group's BoM and budget gives students a closer experience to mechanical engineering design practice in industry [16].

A numerical model is introduced in the first semester of Year 2 to form a simulation of how a part within a machine behaves when subject to compound loads. Further digital simulation, such as, FEA is taught in units other than design. However, the teaching does not extend to digital twins. As noted earlier, digital twin technology is in its infancy, so it is unsurprising it is not seen it in a traditional mechanical engineering degree. That is not to say that awareness of digital twins is not gained in the later optional units. If digital twins are to be taught as part of design teaching, then additional resource would be required to couple the digital simulation with the physical system.

At UWE, engineering drawing (2D and 3D) is learned in a group activity where students each draw a 3D part of an assembly which are then brought together to create a model of the assembly and animation for summative assessment. The 2D engineering drawings are completed throughout but as a non-assessed ongoing activity in which the benefit is in gaining drawing experience. The S1 D&M is individual here, digital technologies are employed to generate stl files for generating a 3D part. In S3, systems design is delivered in which students design a mechanical drive assembly, typically an actuator, gearbox and electric motor. In S4, students are taught digital simulation through computational methods units, by creating FEA and CFD models. In S1 and S2, the number of BEng students is in excess of 300 and they study the Engineering Practice (D&M and engineering drawings) in groups (e.g., tutorial class size 25/50) which ties up teaching resource even more. The D&M exercise is limited to students varying the geometry of one part. This also limits the resource needed to support the activity but does enable students experience of 3D printing parts to their variant design.

At UWE, the BEng degree programmes have a foundation year. In Year 0, is an Engineering Experimentation unit in which students use digital twin technology to gain an awareness of how to control a mobile case assembly production line. The production set-up consists of two assembly lines which are connected by a moving automatic vehicle, see figure 1. It has Siemens software for control (e.g., NX software) and Festo hardware (e.g., pneumatics) and cost in the region of £320K in 2021. This purchase is part of a Siemens Connected Curriculum which give access to their digital software. In this Cyberlab the virtual model is already generated and data-linked to the production line. The students appreciate how the digital twin reacts to the outputs from the physical space output, such as, the production line product flow.

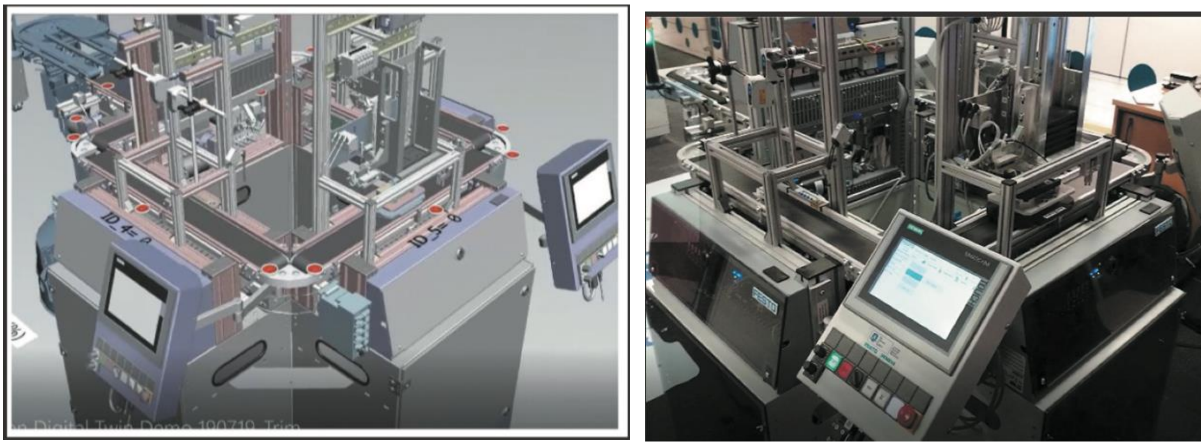

Figure 1. Siemens production line with (a) digital twin technology and (b) physical object

The Siemens Cyberlab is also used for Year 2 teaching, but only for students on the BEng in Manufacturing course. In the DfMA project, students create a manufacturing plan for the production line layout of the digital twin Cyberlab.

4 CONCLUSIONS

The digital environment, in which design teaching is delivered at UWE and Bath, is described in three levels: digital technology, digital simulation and digital twin. Both universities run multiple programmes that are combined to study the design units in a cohort size of over three hundred. To enable large cohorts to use digital technology in their design exercises, planning and technical support is required. In the case of the Design and Make exercise, UWE controls the support required by planning this exercise as a variant design. Here, each student uses digital technology to create a 3D model of a single part only, such as a jar clamp, and then generate an stl file from which the part is 3D printed. In contrast, Bath plans Design and Make as an open group exercise of a mechanical assembly, which needs considerable support from technical staff to procure and manufacture a high number of parts. Similar to UWE's students, Bath students use digital technology to create a 3D model of the assembly and where needed CAM files for 3D printing and laser cutting.

Digital simulation is taught by both universities to upskill students in the creation of FEA and CFD models. At Bath, digital simulation is not taught within the four design units, but by other units. However, in Bath's Design 3 unit, students write their own numerical model to simulate how a part reacts under loading. The idea of the Digital twin, shown in table 2, is introduced by UWE to all foundation year students as part of the Engineering Experimentation unit, in which students gain an awareness of an existing virtual-physical Siemens-Festo system.

The digital environment is predicted to grow significantly in the next decade. Presently, students are taught how to use digital technology to create CAD and CAM files of their designs making them effective in their placement roles. If industry continues to increase its use of digital twins, education may need to include it in the curriculum and deliver it by either creating its own digital twins or, in the case of UWE, decide to invest in an appropriate industrial package.

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