Pedagogy 4.0: Employability Skills and Computer Aided Design (CAD) Education for Industry 4.0

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***Abstract*—The fourth industrial revolution, termed Industry 4.0, is characterised by an exponential transformation rate. As a result, workforces and companies must adapt to rapid changes, which prompted the development of new approaches to higher education, such as Education 4.0. However, despite its importance in enabling Industry 4.0 and related technologies, such as additive manufacturing and smart manufacturing, computer-aided design (CAD), computer-aided manufacturing (CAM), and computer-aided engineering (CAE) education has not undergone responsive changes to its delivery. Consequently, this study aims to support Industry 4.0 by identifying the necessary employability skills and enhancing CAD, CAM, and CAE education. This paper shows (i) the crucial role of higher education in equipping future engineers with the skills for Industry 4.0; (ii) the current state-of-the-art in computer-aided design; and (iii) proposes a novel adaptive approach to computer-aided design, manufacturing, and engineering. Indeed, the results reveal that the most effective teaching method evolves with the learner's ability. As such, the proposed Pedagogy 4.0 empowers students to adapt their learning experience. These findings provide novel insights into engineering education and may contribute to developing the next generation of engineers for Industry 4.0.**

***Index Terms*—Industry 4.0, Computer-Aided Design, Computer-Aided Manufacturing, Computer-Aided Engineering, Additive Manufacturing, 3D Printing, Education 4.0, Engineering Education.**

I. Introduction

Industry 4.0, also known as the fourth industrial revolution [1], is a digital transformation progressing exponentially [2]. This has had a considerable impact on manufacturing [3], [4] and its associated supply chain [5], [6], leading to digitalisation in smart manufacturing [7] and cyber-physical systems [8].

Central to Industry 4.0 is the use of computer-aided design (CAD), computer-aided manufacturing (CAM), and computer-aided engineering (CAE) [9]–[12]. These may also be referred to as computer-aided technology (CAx) [13]. CAD is a fundamental part of the design for manufacturing and assembly (DFMA) [14], rapid prototyping [15], additive manufacturing [16], virtual assembly [17], augmented reality (AR), and virtual reality (VR) in manufacturing [18] and digital twins [19]. Further prospects are also arising with the introduction of the Industry 5.0 concept [20]–[22].

Industry 4.0 has also led to the need for new skills [23], [24] to match the exponential growth in technologies [25]. This has prompted educational developments in Education 4.0 and University 4.0 [26]–[29]. Core pedagogical principles underpinning the development of the necessary digital skills for Industry 4.0 have been identified [30] and include individualised online learning experiences with more significant student input and ownership. These were catalysed by the Covid-19 pandemic [31], calling for more effective online learning. However, despite its prominent role in enabling Industry 4.0, computer-aided technology education has yet to benefit from a responsive change in its delivery [32], [33].

Consequently, this study aims to identify the key computer-aided skills and attributes to equip the next generation of engineers for Industry 4.0 and support their employability in a fast-paced industrial world. This has been a significant focus of engineering education in recent years, advocating for real-world learning [34] through approaches such as problem-based learning [35], [36] and the conceive, design, implement, and operate (CDIO) framework [37], [38]. Moreover, the present research investigates students' perception of the state-of-the-art in CAD education [39]–[41] to eventually offer a novel approach to teaching computer-based skills for Industry 4.0, termed Pedagogy 4.0.

The remainder of this paper is structured as follows. Section II presents the methodology employed. Then, Section III identifies the key skills and attributes for engineering employability, assesses the effectiveness of current CAD education practices, and ultimately proposes a novel adaptive approach to CAD, CAM, and CAE education in an Industry 4.0 context. Finally, the main findings are summarised in Section IV.

II. Methodology

In this study, a combination of qualitative (e.g. surveys and focus group) and quantitative (e.g. learning analytics) research methods are adopted. This work was carried out in the Mechanical and Design Engineering department at Aston University, UK.

A. Stakeholder Survey

An online survey of relevant stakeholders was undertaken at Aston University to ascertain the relevant skills inherent to CAD for employability. The participants were divided into three categories, with the following eligibility criteria:

- *students*, undertaking full-time higher education studies in Mechanical Engineering or Design Engineering at Aston University;
- *academics*, full-time members of staff with teaching duties in the School of Engineering and Technology at Aston University; and
- *industry professionals*, within the mechanical engineering discipline and having a relevant connection with Aston University.

A total of 109 eligible participant responses qualified for this study, with the breakdown provided in Table I. Note that no protected characteristics, such as age or gender, were gathered.

TABLE I
NUMBER OF PARTICIPANTS FOR THE STAKEHOLDER SURVEY.

Participant category	**Number of participants n**	**Percentage of participants**
Students	64	58.7%
Academics	18	16.5%
Industry professionals	27	24.8%
Total	109	100%

B. Student Survey

CAD has been taught using written worksheets [32], pre-recorded videos [39], or a combination of both [40] employing a blended learning approach [41]. The intention for this is to responsibilise learners and allow them to progress at their own pace, hence why CAD is not typically taught during live sessions for large cohorts. More recently, the use of engineering drawings (plan, front, side, and isometric views) for CAD education has been suggested as a relevant strategy, particularly for more experienced CAD users [42].

Consequently, both first-year students ($n = 150$) learning CAD for the first time in higher education and second-year students ($n = 104$) having learnt CAD in higher education for a year were asked to complete a part modelling exercise suitable for their level, using Solidworks [43]. Each year group was presented with the following three resources, namely (i) a written worksheet, (ii) a pre-recorded video and (iii) an engineering drawing of the part. Learning analytics enabled to identify which resources students gravitated towards, thereby assessing their preferences. Furthermore, an online survey following the completion of the exercise offered an opportunity for students to reflect on their learning experiences.

C. Student Focus Group

Lastly, to obtain further insights from the students, a focus group was organised ($n = 10$), gathering students having a strong commitment to CAD. The aim is to better understand their motivations and perception of CAD education, particularly concerning the following:

- their motivations to get involved with CAD beyond their direct academic studies;
- the effectiveness of established CAD teaching methods;
- the evolution of the resources employed as their CAD skills developed; and
- ways to improve engagement with CAD.

III. RESULTS

A. Skills for Industry 4.0

The stakeholder survey very clearly revealed that a degree is the preferred qualification to secure employment in an engineering field for over 70% of each participant group, as depicted in Fig. 1. It is noted that academics tend to favour longer studies and are the only participant group not to value apprenticeships, and also the only participant group to value PhDs. This is understood as a bias arising from their personal experience, as academics typically undertake longer studies.

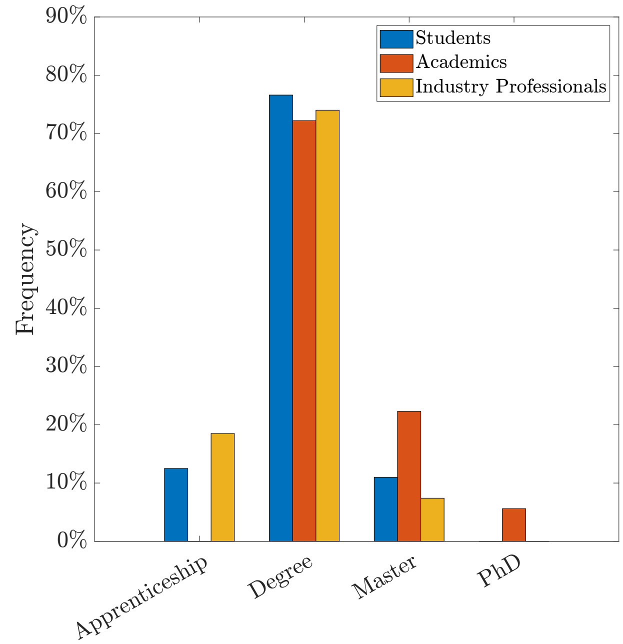

Fig. 1. Preferred qualification for employability in engineering fields according to students ($n = 64$), academics ($n = 18$) and industry professionals ($n = 27$).

Then, stakeholders were allowed to express their views on the CAD software packages deemed to be most crucial for future employment. The results for the proposed list of software are presented in descending order of averaged perceived importance in Fig. 2. It is important to note here that both Solidworks [43] and Ansys [44] are the institutional software packages taught at Aston University, where the survey of the students and academics was conducted. Thus, a bias may occur, which would explain the disproportionate perceived importance of Ansys by academics compared to students and industry professionals, for instance. Nevertheless, there is a significantly higher perceived importance for Solidworks compared to other packages. Therefore, this justifies the relevance of the present study, undertaken using Solidworks to enhance CAD education.

The results of the stakeholder survey have evidenced the central role of higher education in providing students with the necessary skills to secure engineering employment in the context of Industry 4.0 and the relevance of Solidworks as a

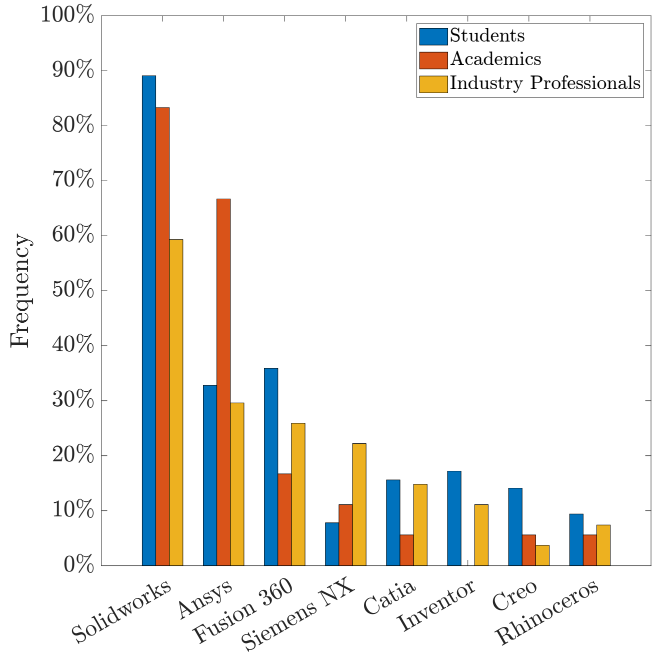

Fig. 2. Perceived importance of computer-aided design software for employability in engineering fields according to students ($n = 64$), academics ($n = 18$) and industry professionals ($n = 27$). Note that Solidworks and Ansys are both institutional software packages at the institution where students and academics were surveyed.

software package. Consequently, the student perception of the current state-of-the-art in CAD education is investigated.

B. Computer-Aided Design Education

First and second-year engineering students were asked to complete a part modelling exercise suitable for their level of CAD experience. Each year group was presented with three different resources: a worksheet, a pre-recorded video, and an engineering drawing of the part. Learning analytics, tracking the use of each resource, enabled the identification of the students' preferred way of learning CAD. Note that overall resource usage is tracked, i.e. students may utilise multiple types. In fact, most students employed a combination of the worksheet and either the video or the engineering drawing. Interestingly, the choice between the video and engineering drawing appears to be dictated by their experience level: first-year students favouring the video, whereas second-year students preferred the engineering drawing. These results are presented in Fig. 3. For both year groups, the use of the worksheet is constant circa. 50%, revealing that the worksheet remains a valuable resource at any stage. However, there is a clear shift in student preference from video to engineering drawing as they progress through their CAD studies.

The students' own reflection supports these findings, identifying the worksheet as most useful unless further details were needed for more advanced tasks: *"Step by step written format is easiest to follow and navigate. Video was helpful only where PDF failed to give details on where to find info"*. Indeed, video-based resources are perceived as *"more detailed"* by students. As students progress through their course and CAD education, engineering drawings provide a more efficient way to capture the necessary information once the use of the software itself has been acquired: *"engineering drawings allow us to figure it out for ourselves."* This supports the gradual shift in students' preference towards engineering drawings, in line with previous work [42], and is vital to offer the individualised learning experience necessary in the context of Industry 4.0 [30]. Finally, it was suggested that combining all types of resources would prove a robust approach: *"a mix of the written PDF and video tutorials along with an engineering drawing to get all the base information."*

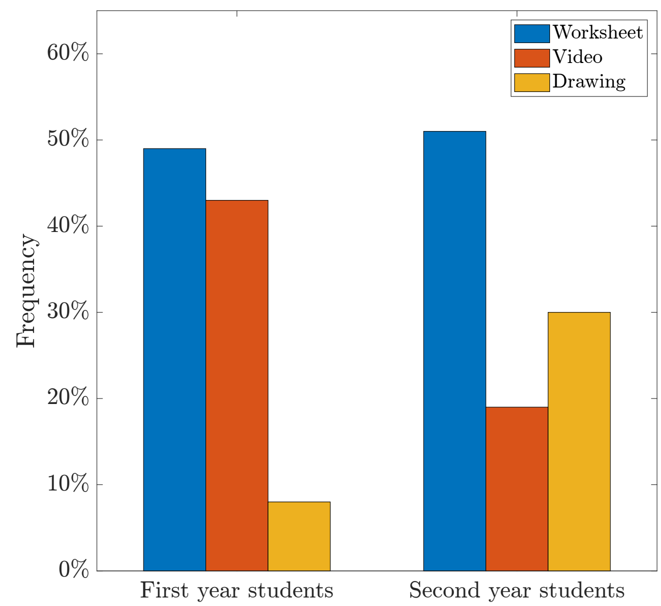

Fig. 3. Students use of CAD resources, based on learning analytics for first ($n = 150$) and second ($n = 104$) year students.

Some students noted that it would be *"better to learn with a live demonstration"*. This may further justify the attractiveness of the videos. However, the reason this option is not explored is two folds. First, it has proven inefficient for large cohorts, where a blended learning approach has been favoured, then focusing on individual support [37]. Furthermore, there has been increasing demand for massive open online courses (MOOC) as part of Industry 4.0 [45], [46].

Student insights have proven valuable to better understand their perception of the state-of-the-art in CAD education. Consequently, to capture more in-depth views, a focus group was undertaken with students that have shown an extra-curricular interest in CAD through the Aston University CAD Society, an extracurricular student society working to improve their CAD skills.

C. Focus Group

The focus group aims to understand what motivates students to engage with CAD beyond their academic studies to enhance CAD education for all. The ten selected participants comprised four first-year, three second-year, and three final-year students, thus spanning the whole course.

Their underpinning motivation to employ CAD is *"to visualize my ideas/thinking and test what I have designed"* and because *"it's an easier way for me to come up with more in-depth designs compared to hand drawn sketches"*. Critically, respondents highlighted the importance of CAD for employability, describing it as a *"useful skill to have both in and after university"*. This supports the results in Section III-A, which revealed the perceived importance of Solidworks to transition into employment.

Participants were then asked about their preferred learning resources. The results in Table II support the findings of Section III-B, namely that more experienced CAD users favour engineering drawings for part modelling. The comparative perception of all three resources is summarised by a student as follows: *"videos can be paused and are more visual. They also keep my attention better than written tutorials. Engineering drawings allow me to actually design a final product and have a final goal."* Another participant stated: *"engineering Drawings make it easy to see and understand dimensions and the video is useful when I get stuck."* There is, therefore, a clear demand for engineering drawing from these advanced CAD users.

TABLE II
PREFERED CAD LEARNING RESOURCES ACCORDING TO FOCUS GROUP PARTICIPANTS ($n = 10$).

Preferred CAD learning resources	**Number of responses**
Engineering drawings	8
Pre-recorded videos	6
Written worksheets	3

To capture whether students are aware of this shift in most useful learning resources as they progress, they were asked to describe how the way their learnt CAD evolved as they became more advanced users. Remarkably, student perception fully supports the results evidenced in Section III-B: *"at the first stage before learning CAD, video tutorials are the best way to teach to show them how/where every function is. As we progress, engineering drawings are easy to read information from"*, and *"in the beginning, more in person and video. As we progress, there should be more engineering drawings that increase in difficulty. There should still be video tutorials and in-person teaching, but it should be optional for the person. This is because our CAD experience and learning methods may vary"*. Therefore, the most efficient way to teach CAD evolves as the students progress. Nevertheless, there remains value in each type of resource, which suggests that an efficient combination to offer an adaptive and individualised learning experience would be the best way to support learners in higher education.

Lastly, means to make CAD education more engaging were tackled. Here, students clearly value the use of CAD as part of additive manufacturing. Indeed, as discussed in Section I, CAD is fundamental to enabling Industry 4.0 technologies such as additive manufacturing. The participants noted that CAD *"allows people to bring their models into real life i.e. 3D print or laser cut. Or create videos of their models"*.

In Section III-A, the importance of higher education to support the development of CAD skills for Industry 4.0 was evidenced. Then, Section III-B evidenced that, as students progress, engineering drawings replaced videos as the preferred CAD learning resource. The focus group in Section III-C confirmed this. Consequently, these findings will be employed in Section III-D to develop an adaptive learning experience to optimally support CAD learners through a Pedagogy 4.0 approach.

D. Pedagogy 4.0

As part of education for Industry 4.0, individualised online learning experiences have been identified as critical [30]. Based on the results of this study, a Pedagogy 4.0 approach, offering an adaptive learning experience, is proposed. The aim is to provide all necessary information while empowering the learner to speed through areas they are confident with while providing all necessary details for areas not yet assimilated. It should be noted that a similar pedagogical approach would benefit learners in other contexts: too easy or too hard a problem for students to solve will lead to disengagement. As student abilities vary, so must the learning activities provided to offer an inclusive and engaging learning experience for all.

The varying effectiveness of the different types of resources with CAD experience and the value of each type of resource has been evidenced. Consequently, integrating all three types of resources in a single document is suggested, yielding a *hybrid* resource. Practically, this is achieved by providing learners with a single document that incorporates various resources, namely:

- an engineering drawing enabling advanced users to model the part solely based on the dimensions, without any further input or guidance required;
- a step-by-step worksheet with the necessary details to complete the exercise; and
- embedded video recordings for each step, in lieu of an illustrative image, so students can easily access additional details if and when required.

The purpose of this approach is to enable students to adapt their learning experience, allowing them to watch a short video for any specific steps they may struggle with while also enabling them to proceed at their own pace. An example of the suggested hybrid approach is presented in Fig. 4. Finally, at course level, the student recommendations in Section III-C suggest that working towards an overall project, with an element of design input flexibility, and ultimately leading to it being manufactured, would be more engaging than a collection of individual exercises. This may, therefore, inform future assessment and curriculum design.

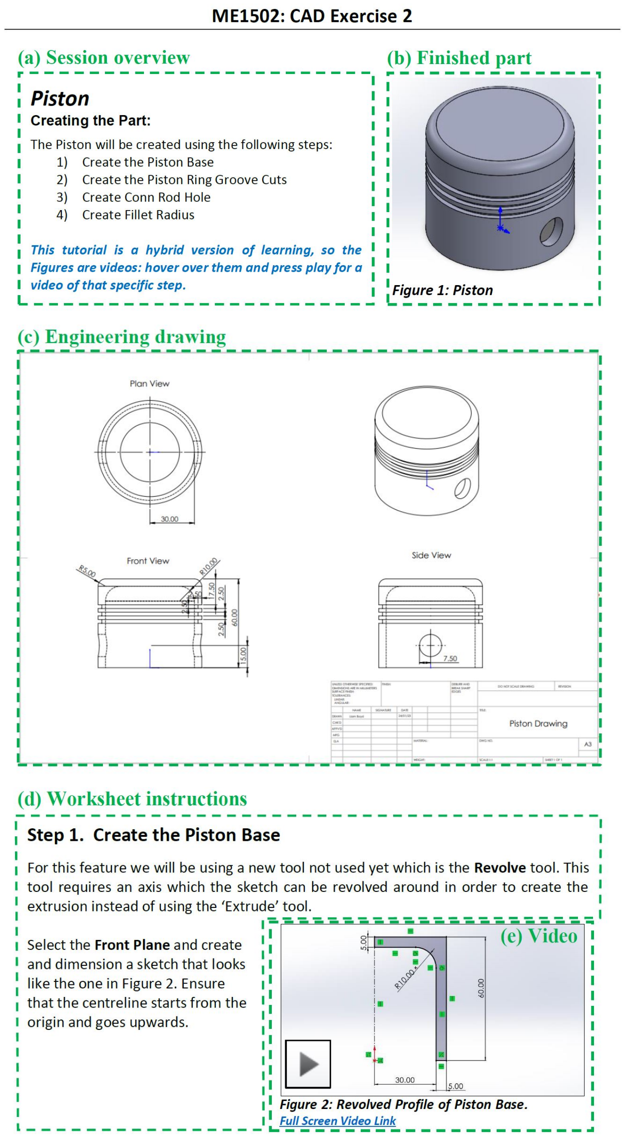

Fig. 4. Example of a hybrid CAD learning resource featuring (a) the session overview, (b) the finished part, (c) the engineering drawing for the part, (d) written step-by-step instructions and (e) videos for each step.

IV. Conclusions

Computer-aided design and associated technologies are central in enabling Industry 4.0, smart manufacturing, and cyber-physical systems, including design for manufacturing and assembly, rapid prototyping, additive manufacturing, virtual assembly, augmented reality, and virtual reality in manufacturing and digital twins. Therefore, this study investigated how to develop the next generation of engineers best, ensuring that they are effectively taught the necessary CAD skills.

First, a stakeholder survey identified a university degree as the preferred qualification to secure employment. Furthermore, an insight into the preferred industry-standard CAD software was obtained, revealing the importance of Solidworks.

Then, the state-of-the-art in CAD teaching was ascertained by offering students various learning resources, namely worksheets, videos, and engineering drawings, to complete a modelling exercise in Solidworks. The results identified a change in the effectiveness of each resource as the students' CAD abilities progressed. Beginners favoured videos, while engineering drawings became increasingly popular as the CAD level advanced.

This was confirmed by the focus group, which supported the above findings while also identifying the value and students' use of the various resources. As a result, a novel, adaptive approach to CAD education was devised. The purpose is to allow learners to tailor their learning experience to their level by integrating multiple types of resources.

Future work intends to assess the proposed hybrid resources' effectiveness and the staff's perception of any associated increase in workload arising from the new proposed resources. Ultimately, the present findings provide novel insights into engineering education for computer-aided design. Also, it is anticipated that they may contribute to developing the next generation of engineers for Industry 4.0.

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