

Article

Integration of 3D Printing and Industry 4.0 into Engineering Teaching

Siewhui Chong ¹, Guan-Ting Pan ², Jitkai Chin ³, Pau Loke Show ¹,
Thomas Chung Kuang Yang ² and Chao-Ming Huang ^{4,*}

¹ Department of Chemical and Environmental Engineering, University of Nottingham Malaysia Campus, Jalan Broga, 43500 Selangor, Malaysia; faye.chong@nottingham.edu.my (S.C.); pauloke.show@nottingham.edu.my (P.L.S.)

² Department of Chemical Engineering and Biotechnology, National Taipei University of Technology, 1 Zhongxiao E. Rd. Sec. 3, Da'an District, Taipei City 106, Taiwan; gtpan@ntut.edu.tw (G.-T.P.); ckyang@ntut.edu.tw (T.C.K.Y.)

³ School of Applied Sciences, University of Huddersfield, Queensgate, Huddersfield HD1 3DH, UK; J.Chin@hud.ac.uk

⁴ Department of Materials Engineering, Kun Shan University, 195 Kunda Road, Yongkang District, Tainan City 710, Taiwan

* Correspondence: charming@mail.ksu.edu.tw; Tel.: +886-6-2050-359

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Abstract: The rapid emergence of Industry 4.0 implies that our engineering graduates need to acquire new competences to adapt to the digital transformation. This paper evaluates the benefits of integrating 3D printing and Industry 4.0 into engineering undergraduate programs. Surveys were conducted to gather the feedbacks and views from academics and students. 75% and 86% of the participating students and lecturers, respectively, have heard about Industry 4.0. 63% of the students were exposed to modules with such elements. Tangible 3D-printed models enable visualization of fundamental theories and concepts. Enhanced 3D drawing skills and rapid 3D-printed prototypes can greatly help students study common processing equipment, manufacturing, maintenance, logistics, and operations. Some limitations were identified such as budgeting, lack of knowledge, and difficulty in changing from traditional pedagogy. This paper thus proposes a blended learning model for integrating Industry 4.0 into engineering teaching, which consists of traditional, online learning, and flipped classroom approaches. Implementation of the model can be started off with cross-multidisciplinary collaborations or expert-led training for the instructors, followed by traditional face-to-face teaching and online learning. Flipped classroom is one of the essential components of the model which encourages learning-by-making approaches such as ‘bring your own device’ and ‘do it yourself’. Integrating Industry 4.0 into engineering teaching can create a student-based learning environment, where students are gradually trained to become proactive and lifelong learners who are more conscious of the environment and economy.

Keywords: 3D printing; 4D printing; engineering education; Industry 4.0; additive manufacturing; teaching; smart; Internet of Things (IoT); blended learning

1. Introduction

3D printing is an additive manufacturing process that produces objects layer by layer. There are various types of 3D printing, such as those utilizing thermoplastic or polymeric materials. The three main 3D printing technologies for polymeric materials are stereolithography (SLA), fused filament fabrication (FFF), and selective laser sintering (SLS). SLA and SLS printers use lasers to solidify or fuse the photopolymer resin and powder, respectively, to create an object. FFF, on the other hand,

produces objects by extruding molten thermoplastics, which then harden immediately. 3D printing has had the most profound impact on the biomedical field. A number of medical schools and centers have adopted 3D printers in their education and training programs. The Centre for Image Guided Innovation and Therapeutic Intervention of the Hospital for Sick Children, Toronto, Canada, uses inkjet 3D printing to develop and create tools for surgical training and planning [1]. Various universities are using 3D printing in anatomy education. Australia's Macquarie University and Western Sydney University use 3D printing as part of a long-term education project in anatomy education on printing pre-scanned bones [2]. Monash University developed a novel means of 3D printing cadaveric orbital dissections suitable for education and training in ophthalmology or optometry [3]. Various science, technology, engineering, and mathematics academic institutions are placing high expectations on 3D printing to enhance the learning experience of students [4]. Gillet [5] summarized the work of the European Federation of Chemical Engineers Working Party on Education over the past decade and identified three important factors for educating chemical engineers: curriculum development, personal development, and lifelong learning.

Schelly et al. [6] conducted a three-day 3D printing workshop augmented with online instructional and visual tools designed for middle school and high school level educators. They showed that open-source 3D printing technologies have the potential to improve education through cross-curriculum engagement and active participation. Loy [7] showed how 3D printing can blur the boundaries between the digital and physical world, bringing eLearning and eMaking into product design education. Verner and Merksamer [8] showed that the conceive–design–implement–operate approach can be applied to balance learning pedagogical fundamentals, training technological skills, and teaching practice.

On the other hand, in 2013, a research group at the Massachusetts Institute of Technology, led by Dr. Tibbitts [9], initiated 4D printing, which has benefited the development of smart materials. 4D printing is an advancement of 3D printing, where the fourth dimension is 'time'. In the presence of a stimulus (e.g., heat, ultraviolet light, or water), the printed shape is time-dependent, and thus adjustable, which makes it a dynamic structure with adaptable properties and functionality [10,11]. This advancement has widened the applicability of digital manufacturing, but it requires multidisciplinary knowledge and skills (for instance, mathematics, mechatronics, and mechanical and chemical engineering). A number of new smart engineering materials have since been demonstrated and investigated, for instance, smart valves to control hot and cold flow [12] or acidic and basic flow [13], adaptive pipes [14], sensors [15,16], and soft robots [17,18]. Open source tools have also been developed for platform-based product design linking hardware and software, such as I3Mote [19].

The concept of a 'smart factory' has led to Industry 4.0, a collective term for the Internet of Things based on cyber-physical systems (CPS) that bridge digital and physical environments [20]. As shown in Table 1, Industry 4.0 can be summarized to contain nine pillars—advanced robotics, additive manufacturing, augmented reality, simulation, horizontal/vertical integration, industrial internet, cloud, cybersecurity, and big data and analytics [21,22]. The term Industry 4.0 and its reference architecture model originate from "Industrie 4.0", a project launched by Germany in 2011 to digitalize manufacturing [23]. Industrie 4.0 in Germany is based on High Tech 2020 Strategy, in which it is considered a strategic measure to consolidate and integrate the high-tech sectors, ensuring the country's technological leadership. Similar strategies are also laid out by other countries, such as "Smart Nation Program" in Singapore, "Industrial Value Chain Initiative" in Japan, "Made in China 2025" in China, and "Smart Manufacturing" in the United States. In Malaysia, most of the manufacturing sectors range from mass production to automation. A national governmental policy on Industry 4.0 is currently being formulated and the relevant parties are undertaking various outreach programs to increase public awareness; the government is also engaging various stakeholders to seek their view and feedback on Industry 4.0 [24].

Gearing towards sustainable developments, Industry 4.0 is able to shape a framework of production planning and control with carbon tax [25]. Companies' strategic, operational, environmental, and social opportunities are identified to be the positive drivers of Industry 4.0 implementation in companies [26]. Industry 4.0 not only affects production and employment, but also education and various aspects of everyday life. Despite the increasing adoption of additive manufacturing in biomedical schools as an effective teaching aid, in engineering education, additive manufacturing and Industry 4.0 have received only limited attention due to the misconception that it only applies to automation and mechanical engineering, and also limited knowledge especially on the Industry 4.0 pillars. Some universities are starting to integrate Industry 4.0 into their teaching and research, for instance, the establishment of the fully automated Industrie 4.0 Learning Factory at the University of Applied Sciences Darmstadt [27] and the Smart Production Laboratory for teaching and research at Aalborg University Denmark [28].

Table 1. Pillars of Industry 4.0 (adopted from [29]).

Pillars of Industry 4.0		Description
1	Advanced Robotics	<ul style="list-style-type: none"> • Autonomous, cooperating industrial robots • Numerous integrated sensors and standardized interfaces
2	Additive Manufacturing	<ul style="list-style-type: none"> • 3D printing, particularly for spare parts and prototypes • Decentralized 3D facilities to reduce transport distances and inventory
3	Augmented Reality	<ul style="list-style-type: none"> • Augmented reality for maintenance, logistics, and all kinds of standard operating procedures • Display of supporting information, e.g., through glasses
4	Simulation	<ul style="list-style-type: none"> • Simulation of value networks • Optimization based on real-time data from intelligent systems
5	Horizontal/Vertical Integration	<ul style="list-style-type: none"> • Cross-company data integration based on data transfer standards • Precondition for a fully automated value chain (from supplier to customer, from management to shop floor)
6	Industrial Internet	<ul style="list-style-type: none"> • Network of machines and products • Multidirectional communication between networked objects
7	Cloud	<ul style="list-style-type: none"> • Management of huge data volumes in open systems • Real-time communication for production systems
8	Cybersecurity	<ul style="list-style-type: none"> • Operation in networks and open systems • High level of networking between intelligent machines, products, and systems
9	Big Data and Analytics	<ul style="list-style-type: none"> • Full evaluation of available data • Real-time decision-making support and optimization

3D printing/Industry 4.0 can greatly help to boost active student learning but there are some limitations which need to be encountered for effective implementation. Realizing the essentiality of preparing our students to fit in to the Smart Factory demands and the usefulness of Industry 4.0 in conceptualizing the research work, this paper provides a blended model as a reference guide for integrating the elements of Industry 4.0 into engineering teaching while evaluating the impacts and

limitations. The paper is structured to begin with the detail of the survey activities, followed by the survey analysis results and discussion on the benefits of integrating 3D printing/Industry 4.0 into engineering teaching. Following that, recommendations on how to integrate these elements are presented and discussed. Finally, conclusions are given to summarize the work and provide a future direction.

2. Surveys

In most engineering courses, Year 1 covers the basic principles, fundamentals of operations, and engineering mathematics; Year 2 covers the operations with considerations of materials and safety; Year 3 covers product development, process design, and engineering applications with further considerations of control, the environment, and safety; and Year 4 covers advanced topics that expand specific industrial applications. In order to evaluate the impact of integrating 3D printing and Industry 4.0 into a curriculum on engineering teaching and learning, surveys and interviews were conducted (see Table 2). The surveys were created by the authors using Qualtrics software and emailed to all engineering students. 14 academics and 54 student participants took part in the surveys which were opened for two weeks. Group discussions with six selected student participants were conducted to collect their feedback and opinions.

Table 2. Survey details—participants' background and questionnaire

Type	Participants' Background				
	Mechanical, Materials, and Manufacturing Engineering	Chemical and Environmental Engineering	Electrical, Electronic, and Mechatronics Engineering	Civil Engineering and other streams	Total number of participants
Academics	2	7	3	2	14
Students	16	20	8	9	54
Students' questionnaire					
Part A: Fields of application					
A1	Have you heard of Industry 4.0?				
A2	Which modules that you enrolled in made use of 3D printing/Industry 4.0?				
A3	What models/elements of Industry 4.0 have you been exposed to?				
Part B: Impacts					
B1	How do you think 3D printing/Industry 4.0 helps your learning?				
B2	What non-academic aspects of 3D printing/Industry 4.0 have an impact on you?				
Part C: Recommendation					
C1	How would you rate the suitability of 3D printing/Industry 4.0 in engineering education?				
C2	How should lecturers adopt Industry 4.0 (3D or 4D printing, smart systems, cloud, big data, etc.) into their teaching?				
Academics' questionnaire					
Part A: Fields of application					
A1	Have you heard of Industry 4.0?				
A2	In which modules did you make use of 3D printing/Industry 4.0?				
A3	What models/elements of Industry 4.0 have you used for teaching purposes?				
Part B: Impacts					
B1	How do you think 3D printing/Industry 4.0 helps your teaching?				
B2	Do you think there are disadvantages of this technology?				
Part C: Recommendation					
C1	How would you rate the suitability of 3D printing/Industry 4.0 in engineering education?				
C2	Do you plan to use these technologies in your future modules?				

3. Results and Discussion

In this section, the survey results are presented and discussed. The fields of application of 3D printing and Industry 4.0 in the curriculum are first revealed, followed by the evaluation of its impact on teaching and learning.

3.1. Fields of Application in Teaching and Learning

Figure 1 and Table 3 show the Part A results of surveys. 75% and 86% of the students and lecturers heard about Industry 4.0, respectively. 63% of the students were enrolled in modules with 3D printing/Industry 4.0 elements. These modules are mainly related to materials, design, and manufacturing, such as design projects, applied mechatronic construction projects, building information modeling, applied electrical and electronic engineering, and robotics. The students were also exposed to Industry 4.0 in many extracurricular activities, such as makers clubs, Robotics Society, talks, and competitions.

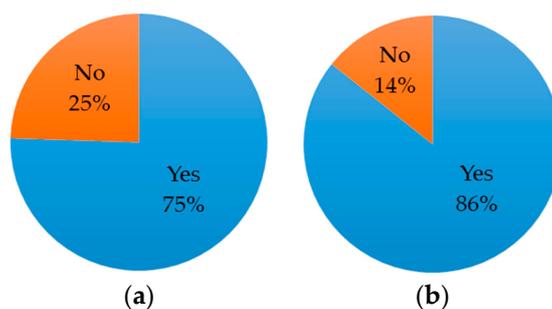


Figure 1. Part A survey results for Question A1. (a) From students; (b) from academics.

Table 3. Part A survey results: fields of application.

Question	Summary of the Responses from Students and Lecturers
A2	<p>% of students involved in 3D printing/Industry 4.0 modules and curriculum: 63%</p> <p>Curriculum (28%): Group/individual design projects, applied mechatronic construction projects, building information modeling, applied electrical and electronic engineering, materials and manufacturing, air-land robot team, design and manufacturing, and process engineering laboratories</p> <p>Clubs and activities (35%): Nott's Makers, Institution of Engineers (IEM) student chapters, Robotics Society, and some education talks and competitions</p>
A3	<p>Prototype (46%): Demo house, sensor holders, some mechanical parts, BIM models for simulation of structures, holder for a pneumatic cylinder, robotic arm, propeller models, artificial limbs, and embossing for RFID system</p> <p>Method (7%): Automation in setting layers of carbon fiber reinforced polymer</p> <p>Decorative object (36%): Butterfly, keychain, name tag, Dota2 logo on keychain, rotating stand, Minecraft sword, book rack organizer, camera holder, sprockets, motor brackets, battery holder, and cases</p> <p>Intelligent items (11%): Automated machines, sensor-based lighting, line-following sensor, and setting up of algorithms to respond to changes during a process</p>

89% of modules incorporated 3D printing, and 11% incorporated artificial intelligence. The most common activities are 3D printing of prototypes (46%), such as mechanical and structural parts, artificial limbs, propellers, and robotic arms, some decorative objects (36%), and investigation of the method of printing (7%). Artificial intelligence was incorporated in applications such as sensor-based lighting and algorithms.

3.2. Impacts on Teaching and Learning

The results of Part B surveys are presented in Figures 2 and 3. Students found that the largest benefit comes from rapid prototyping for in-depth studies (34%), followed by enhancement of computer-aided design (CAD) drawing skills (24%), visualization for better understanding (21%), and troubleshooting and optimization (21%). Similarly, lecturers found that 3D printing/Industry 4.0 helped catch students' attention via the learning-by-making approach (37%), easier concept teaching

via visualization (42%), and promoting students' independent learning (21%). The following sections discuss the relevant impacts of 3D printing/Industry 4.0 on engineering teaching and learning.

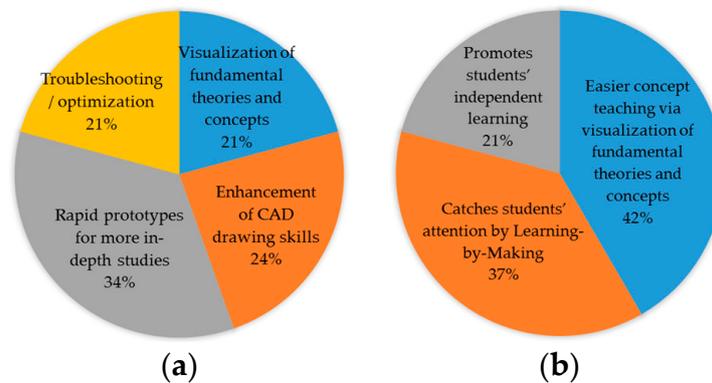


Figure 2. Part B survey results for Question B1. (a) From students; (b) from academics.

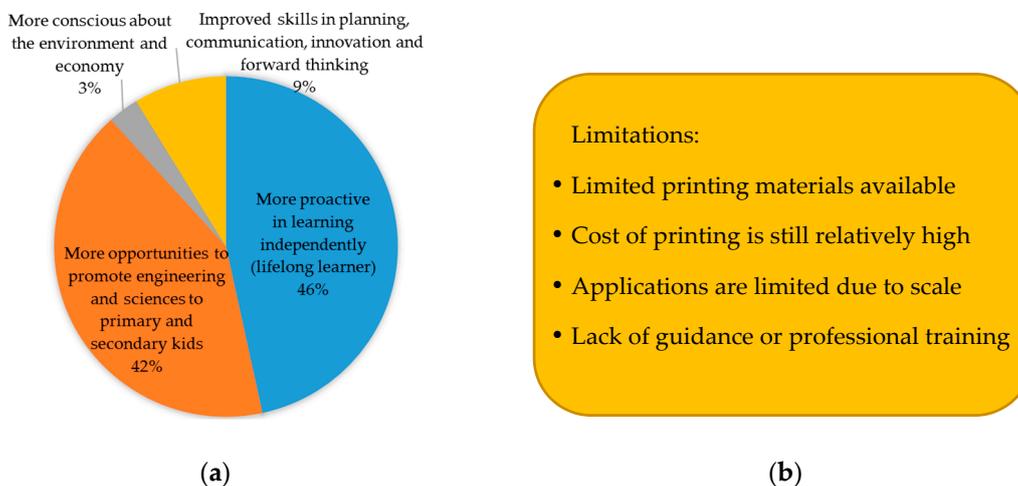


Figure 3. Part B survey results for Question B2. (a) From students; (b) from academics.

3.2.1. Tangible Models for Theoretical and Conceptual Teaching

One of the biggest challenges in engineering teaching is being able to successfully convey engineering concepts to students who have little understanding of the topics. Computerized design and simulations have overtaken physical demonstration models [7]. 3D printing easily and quickly produces customizable models for teaching fundamental concepts to students in an interactive manner. 3D-printed models have been shown to be superior for concept teaching, especially for concepts that require spatial visualizations, compared to the use of virtual and digital conceptualization software [30]. Some interesting examples are printing teaching materials or prototypes which are science or engineering related. In the modules involved, various useful prototypes were designed and printed, including a hybrid microfluidic device, shown in Figure 4a, for understanding double emulsion; a robotic bird, shown in Figure 4b, for learning mechatronics; and a distillation column with a perforated tray, shown in Figure 4c, for demonstrating the working principle and mechanisms of separation.

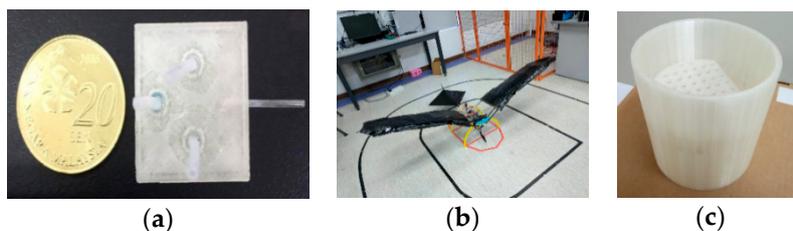


Figure 4. Various 3D-printed prototypes for engineering applications. (a) Hybrid microfluidic device for two-phase study (designed by M. Q. Ko, P. K. Sia, and P. S. Teh); (b) robotic bird for flight control system study (designed by F. Z. Kamali, F. Z. Lim, S. W. Chai, and Z. Y. Ow); and (c) inside of a distillation column with a perforated tray (designed by J. H. Yap).

3.2.2. Enhancement of CAD Drawing Skills

Most engineering programs train students in 2D CAD model development. Students learn one or two CAD software packages, such as SolidWorks, AutoCAD, ANSYS workbench, or COMSOL Multiphysics, to draw equipment, process flow diagrams, and process and instrumentation diagrams for engineering design and/or simulation. The focus is mostly on 2D parts.

Student A commented: “I only learned the basics of 2D AutoCAD in lectures. Out of personal interest, I learned to draw 3D models myself to be able to print them with a 3D printer. Later, I found its usefulness in my engineering studies. My groupmates and I demonstrated our process plant using 3D printed models.”

3D drawing training is useful, especially when analyzing situations beyond design, such as simulating fluid flow and making product prototypes, as it offers more precision and control. 3D CAD drawing skills are useful for students who apply for consultancy and engineering design jobs. Figure 5 shows a CAD model of a solar LED butterfly vest design that incorporates a renewable energy element with an engineering design, showing the capability of CAD drawing.

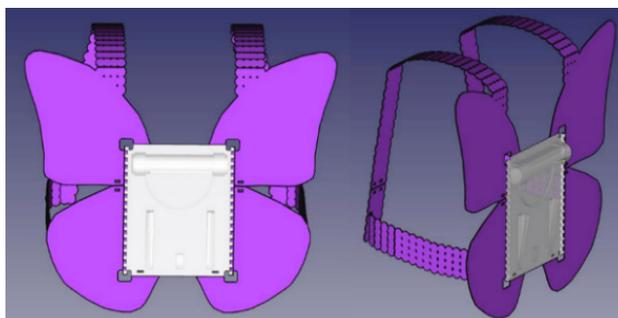


Figure 5. Solar LED butterfly safety vest design (designed by S. Chong, G. T. Pan, and Y. H. Cheng).

3.2.3. Improvement of Troubleshooting and Optimization Skills

To make a product, various aspects need to be considered, such as functionality, price, interface, design and appearance, structure, manufacturing processes, sustainability, and ethics. This involves a range of challenges:

- Integration of technologies—processing, mining and quarry, etc.
- Utility—power generation, water treatment, waste management, etc.
- Factory and manufacturing—automation, production machinery, packaging, raw material, transportation, maintenance, logistics, etc.
- Sustainability and ethics—product/material design, environmental and human health regulations.

Student B commented: “3D printing or Industry 4.0 gives us a rough physical layout of how a site or process would be, thus allowing us to foresee errors that may occur before the plant is built. Also, we can show this model to an investment company”.

As most manufacturing companies use 2D sketches for the fundamental design, certain issues are unidentified and can only be solved in the construction and operation stages. Systematic plant layout planning could aid in visualizing a project proposal, providing an overall picture of a plant before an optimization study. It can be used to assist in cost reduction, and the control of productivity with the available resources. As most processes involve transportation, there is a time gap; this can be accounted for through systematic plant layout planning. 3D printing and Industry 4.0 aid such planning and process design through 3D-printed table-top models or Industry 4.0 elements such as simulation, horizontal/vertical integration, and the industrial internet, thereby enhancing the design, teamwork, and decision-making skills of students. A printed/simulated plant model with interconnected equipment and pipelines can further help students assess potential risks and carry out detailed hazard and operability studies and cost evaluations, as they can see how all elements are interrelated.

3.2.4. Improvement of Lifelong Learning Skills

The results indicate that both students and lecturers found that 3D printing/Industry 4.0 has helped improve students' lifelong learning skills, such as being more proactive and independent and able to plan ahead, while invoking a more innovative and forward-thinking mindset.

Student C commented: "I become more precise when planning out things, taking into consideration the uncertainties in real life of the end product. Also, it makes me realize the importance of planning ahead before executing something." Student D said: "It allows me to think more outside the box. Once I did not believe that such tactics were possible within the manufacturing industry, but now I can come up with more innovative ideas."

3.2.5. Increase of Consciousness on the Community and Environment

The students initiated a number of community projects. They showed that they are proactive and lifelong learners by contributing back to society by setting up a maker community (Nott's Makers), teaching younger kids some engineering design and 3D printing skills (as illustrated in Figure 6), and encouraging them to turn their ideas into reality through a learning-by-making approach. Furthermore, some students initiated the recycling of plastics and a lifecycle of plastics project, turning used plastics into usable and sustainable products via 3D printing.



Figure 6. A camp organized by Nott's Makers for teaching young kids 3D printing, science, and engineering skills.

Student E commented: “It pushes us to realize the importance of not only minimizing cost, but making sure that the production line is sustainable to save Mother Earth. This awakening came when I was exposed to various statistics on the severity of construction projects on environment issues, through 5D (including cost and effects) simulation.”

4. Recommendations for Integrating Industry 4.0 into Engineering Teaching

As shown by the results of A1 and A3 in Figure 1 and Table 3 respectively, Industry 4.0 is slowly becoming mainstream, affecting production, employment, and various aspects of life. Integrating such elements into teaching or education is of utmost importance as it can prepare graduates with the skills required for Industry 4.0.

Figure 7 shows that 49% and 29% of the students and lecturers, respectively, found 3D printing/Industry 4.0 to be highly suitable for engineering teaching and learning; 36% and 75% of the students and lecturers, respectively, found it to be suitable to some extent. On average, the level of suitability of integrating Industry 4.0 into engineering teaching, rated by the students and lecturers, reached about 80–87% (highly suitable: 100%; unsuitable: 0%).

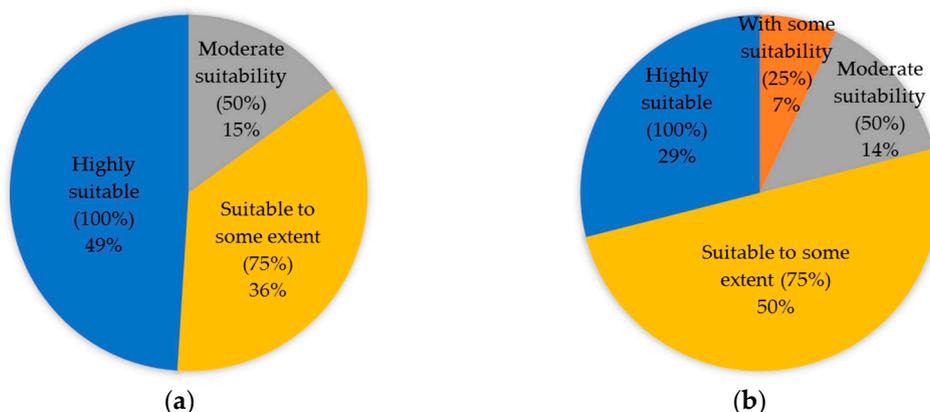


Figure 7. Part C survey results for Question C1. (a) From students; (b) from academics.

Figure 8a shows the recommended activities given by the students to include Industry 4.0 in their curriculum. Figure 8b on the other hand shows that 29% of the academics' plan to use the technology while 71% have shown interest to use it. Some lecturers have incorporated such elements into their teaching modules. However, mostly 3D printing and Industry 4.0 were used in generating prototypes for research purposes (final-year research and postgraduate research). The integration of 3D printing and Industry 4.0 into teaching is still not well practiced due to several limitations. For instance, instructor training is essential for obtaining a certain level of knowledge and skills on the Industry 4.0 technologies. For additive manufacturing, the choices of materials, colors, and finishing surfaces are limited. Some thermoplastics emit harmful volatile organic gases or particulates during printing (especially when printing with acrylonitrile butadiene styrene), and thus it is recommended that printers be operated in a well-ventilated area. Most table-top 3D printers have small build volumes (within $20 \times 20 \times 20$ cm), and are thus unsuitable for large structures. There is also a lack of guidance regarding how the technologies work, especially the other pillars of Industry 4.0. Insufficient budget is one of the major problems hindering the establishment of the required facilities for teaching and learning. Scheduling issues such as difficulties in introducing new contents and skills in the educational programs, and the reluctance of moving from the traditional pedagogy, are also major concerns.

Taking these limitations into consideration, a recommended model is provided in Figure 9 as a guide for integrating Industry 4.0 pillars into engineering teaching. As shown in Figure 9, the model begins with instructor training via multidisciplinary collaborations and expert-led training. The former involves knowledge sharing in the form of research or collaborative work. The latter refers to training given by Industry 4.0 or technological experts who work in the relevant fields. The expert-led training

can include activities such as courses or a knowledge-sharing platform (e.g., a forum or regular meeting) to link the academic curriculum with a real scenario.

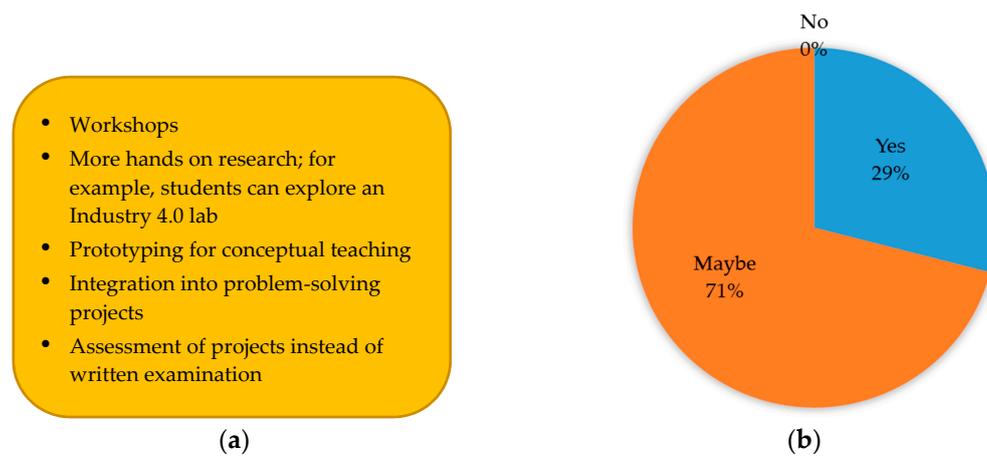


Figure 8. Part C survey results for Question C2. (a) From students; (b) from academics.

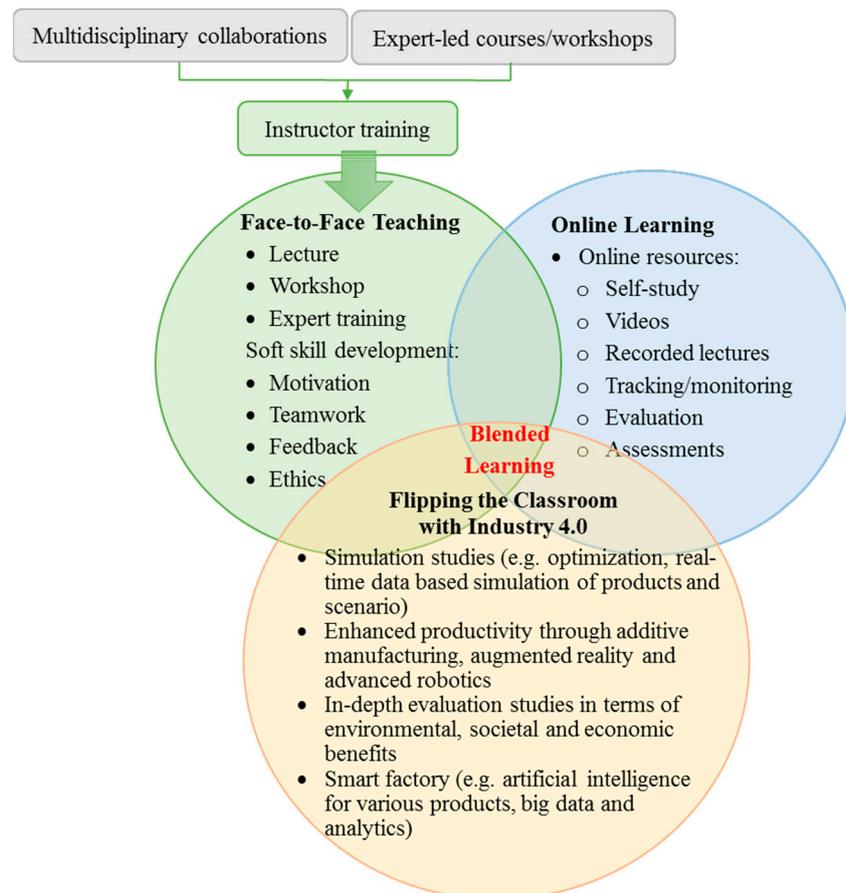


Figure 9. Recommended model for integrating Industry 4.0 pillars into engineering teaching.

Following instructor training, a blended learning model is suggested for an engineering curriculum, which consists of (1) face-to-face teaching; (2) online learning; and (3) flipping the classroom with Industry 4.0. Face-to-face teaching refers to the traditional approach consisting of lectures and workshops, as well as some group activities to develop students' soft skills. Online learning refers to the use of an online learning management system (e.g., Moodle or Blackboard) for students' self-learning, assessment, and evaluation. The third component of the model is the

flipped classroom approach, which refers to hands-on student-led projects, with the guidance of a trained instructor/lecturer. 'Bring your own device' (BYOD) is a pedagogical modern trend that enhances active learning. For instance, the use of open-source software and easy-to-use devices like Arduino chips, could be applied for automation or control system learning. This type of devices also contributes to sustainability due to their low-cost features. BYOD is also linked to the 'do it yourself' (DIY) approach where learning by making is implemented, for instance, making a robotic arm via additive manufacturing, applying artificial intelligence, and evaluating its environmental and social impacts when being used in manufacturing plants. With these approaches, some real-world problems can be modified and used as students' projects or assignments, which can be assessed to (partly) replace traditional written examinations.

Student F commented: "In my opinion, I believe that students who are constantly exposed to Industry 4.0 have more opportunities in their future career. Companies are investing in emerging technologies to streamline company activities. A report from Siemens U.K. found that advanced and emerging digital technologies, such as 3D printing and robotics, are implemented to improve and raise manufacturing activities in U.K. companies. Thus, students who have experience in Industry 4.0 have a higher chance to be employed by big and advanced companies."

A number of relevant Industry 4.0 elements for engineering teaching can be used, for instance, simulation studies on real-time data and optimization; enhanced productivity studies through additive manufacturing and advanced robotics; maintenance and logistics studies through augmented reality; smart-factory-related technologies such as artificial intelligence, big data, and analytics; and evaluation studies on the environment, society, and economics.

This model could also be beneficial to enterprises and companies, where the personnel (both operators and engineers) require training and learning about these advanced topics. Also outlined in [31], practical 'learning factories' toward the understanding and implementation of Industry 4.0 are essential to enable personnel to learn and transfer learned knowledge directly to the own workplace.

5. Conclusions

Industry 4.0 has recently emerged for flexible mass production of better products with reduced time and development cost. This also means that students, especially engineering graduates, need to acquire new competences. However, most engineering programs are not prepared for the change yet. In our engineering programs, only 28% of the teaching modules involved 3D printing/Industry 4.0 elements, mainly due to the limitations of insufficient knowledge and skills, scarce budgets, and scheduling issues. This paper thus investigated the applicability of integrating 3D printing and Industry 4.0 into engineering teaching. Surveys involving 14 academics and 54 students were conducted to evaluate the impacts of 3D printing/Industry 4.0. Suggestions and feedback for integrating such elements into teaching were collected and analyzed. 3D printing helps engineering students learn via rapid prototyping and enhances CAD drawing skills, troubleshooting, and optimization. Industry 4.0 is a useful starting point for teaching, where the student is encouraged to bring new information and ideas back to the classroom and discuss any conflicts with the lecturer. This type of self-education is important as it initiates student-based learning and creates proactive and lifelong learners who can see and value an opportunity through self-initiatives, frame a problem, construct the process and production design, map development, and troubleshoot any problem that may arise. With the goal of sustainable manufacturing, Industry 4.0 is a good tool to teach sustainability to the students via learning by planning an approach using environmental-friendly process routes or materials, and by simulating or evaluating their impacts on the environment, economics, and society. Students exposed to Industry 4.0 will have opportunities for self-initiated research and gain experience in product design, technological development, smart manufacturing, as well as identifying problems and troubleshooting for creating a sustainable future.

The professional development of the lecturer is also an important element for technological and digital transformation. There needs to be a transition period of which the lecturers are willing to

facilitate the process of changing their pedagogy and teaching practices comfortably. A blended classroom model that consists of traditional teaching, online learning, and flipped classroom approaches is suggested for integrating the pillars of Industry 4.0 into an engineering curriculum to better prepare graduates.

Cross-disciplinary collaborations, for instance, with the computer science department, can serve as the first step towards implementing this approach. Once the instructors are trained, they can then revamp their teaching materials to include Industry 4.0 elements. The students can learn via the blended classroom approach, which is a mix of traditional teaching, online learning, and flipped classroom method such as BYOD and DIY.

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