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Towards 5.0 skills acquisition for students in industrial engineering: the role of learning factories

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Abstract

In recent years, there has been an increasing transition towards the Industry 5.0 paradigm, which focuses on technology and sustainability but also on the resilience and human-centricity of the production and logistics processes. These changes require investment in equipment, process change, and new skills. To avoid the mismatch between the skills required by industry and the skills offered by university courses, recently, learning factories (LFs) have been spread worldwide, aiming at promoting hand-on learning approaches to manufacturing, logistics and technological processes. This paper illustrates how LFs can support the development of contents and competencies useful in the transition to Industry 5.0 in the industrial engineering courses. Starting from the description of a LF installed in Italy, this study presents a systematisation of the contents that can be addressed by adopting LF in the design of learning modules specifically facing the requirements and skills of the different Industry 5.0 areas.

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Keywords: Learning factories, Industry 5.0, Competencies, Skills, Industrial engineering, Training

1. Introduction

The manufacturing sector has undergone a significant transformation in recent years, due not only to the digitalisation of production and logistics processes and the technological innovations that have taken hold in the sector but also to the growing interest in sustainability, resilience and human-centricity design of manufacturing processes [1]. Climate change, as well as the Covid-19 pandemic and the war in Ukraine, have greatly accelerated transition processes and shown how technologies can be a valuable contribution not only to make industrial systems more efficient or to lower production and transport costs, but also to improve the sustainability and resilience of processes

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without losing sight of the well-being of the workforce. However, these changes are rapid and require quick adaptation in terms of technology and the skills needed to fully exploit the benefits of implementing new technologies maintaining high levels of workers' well-being to avoid skill mismatches and organisational inefficiencies.

Skill mismatch refers to "the gap between supply and demand for skills and the fact that observed matches between available workers and available jobs offered by firms in terms of skills and qualifications are sub-optimal" [2]. These issues are particularly critical because skills constraints affect companies' ability to innovate and adopt technological development, employability prospects, and access to quality jobs for workers. The need to have a workforce with the most appropriate skills to perform specific tasks must also consider that technological innovation is a continuous process that often proceeds even by small incremental innovations, new updates and releases of the same technologies already adopted. This continuous and incremental updating of technologies also requires a continuous updating of skills on the part of workers, a 'continuous learning' that must continue throughout their working careers, commonly referred to as long-life learning, and workplace-based training and professional development [3].

Consequently, the world of higher education has also had to undergo a significant change to consider technological transformations and the demands of manufacturing companies by providing knowledge, competencies and skills that are ever closer to the world of work and the frontier of innovation. Therefore, the term Education 4.0 has started to indicate a new framework of advanced manufacturing education based on critical technologies enabling knowledge to be effectively transmitted to new engineers, increasing their familiarity with them while also creating a more appealing image of the manufacturing sector. This education system creates a sustainable environment that will accelerate its adoption in manufacturing [4].

In this context, Learning Factories (LFs) are a promising tool to promote the teaching of industrial processes and activities in manufacturing by constituting a learning environment for and a model of socio-technical systems [5]. Indeed, LFs make it possible to study and deepen some typical manufacturing production and logistics processes with a work-based learning approach in which the working and learning places are entirely separated, and no working or value-creation task is professionally executed [6]. However, since 1994, when these tools began to spread, more and more LFs have been classified according to the processes and products they deal with and the educational and research objectives they aim to pursue[7]. It is, therefore, not easy, once approaching LFs environments, to understand what research and didactic uses can be made of it, what competencies they enable and what learning contents can be developed from the implemented processes and technologies. In this article, we will try to answer to the following research questions:

RQ1. What are the potential research and teaching paths related to Industry 5.0 in Industrial Engineering that can be developed through the implementation of a Learning Factory (LF)?

RQ2. What learning contents and competencies can be enabled by its use based on existing scientific literature and experiences?

In particular, after this introduction, Section 2 will report the methodology used to conduct this research, while Section 3 will provide background concerning the existing scientific literature about the LFs. Section 4 will describe the SIF400 LF located in the University of Bergamo. Section 5 will contain the main results of this research work: for each industrial engineering area and Industry 5.0 pillar, the main learning contents offered by the SIF400 LF have been identified along with the main technical, methodological, personal and social competencies enabled. In Section 6 discussion and conclusion of the research work will be discussed.

2. Methodology

In order to reach the main goal of the research, we based our research workflow on the indication proposed by [6], which defines the future-oriented research and education of the LFs (Fig. 1).

Our research work began by utilising the CIRP CWG (Collège International pour la Recherche en Productique Collaborative Working Group) classification [6] to categorise our LF, which is one of the most comprehensive classifications available, as discussed in Section 3.1. Through this classification, we were able to gain a better understanding of the different components, processes, and educational goals of LFs.

After conducting a thorough review of scientific literature pertaining to LFs, we shifted our focus to analysing our own LF, the SIF400 LF by SMC company. The findings from this analysis provided us with a deeper understanding of our facility's unique features, which we could further explore.

To gain a comprehensive understanding of the potential learning opportunities that the SIF400 LF offers in various areas of industrial engineering, we defined the main industry 5.0 pillars involved and the different possible learning contents in terms of manufacturing processes and technologies. By doing this, we were able to identify the key areas where learning could take place.

Finally, we identified a range of competencies that students and all potential learners could acquire from the previously identified learning contents. We analysed these competencies through the lens of technical, methodological, personal, and social competencies, which helped us gain a better understanding of the full range of skills that could be developed through our LF. As a result of this analysis, we gained a deeper appreciation for the value that our LF provides.

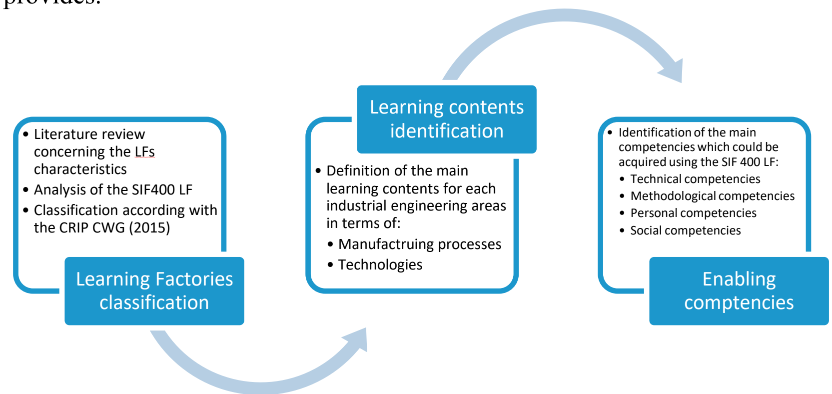

Fig. 1. Research Workflow

3. Background

The widespread adoption of digital and automation technologies under the Industry 4.0 paradigm has prompted both educational systems and companies to look closely at the new skills workers must and will need in the future to perform their jobs efficiently and effectively. Competencies and skills models have been developed through the years (e.g., [8, 9]) to define the set of desired competencies that are highly relevant in Industry 4.0 and should be appropriately developed to meet the challenge of creating a Human Capital 4.0 [10]. In particular, several studies showed that technical skills must be accompanied adequately by solid methodological, personal and social skills to increase business value in the long term [11].

In this context, the concept of Education 4.0 has been developed to promote the improvement of learning activities by exploiting the use of digital technologies based on the nine principles [12]. Among them, project-based learning and practical and experimental experiences are strongly interconnected and could be adequately supported by the implementation of realistic environments, such as LFs.

Indeed, recently, LFs have gained significant popularity in universities and industrial companies worldwide [13]. These immersive environments are designed to replicate real-life production systems, providing valuable hands-on experience in industrial settings [14]. LFs serve various purposes, encompassing a wide range of topics such as product design, production processes, and even the end-of-life phases [15]. Indeed, LFs realistically replicate factories, simulating the production of commercial goods usually on a smaller scale but eliminating potential risks and limitations that might impede students' active engagement [16]. This aspect allows students to acquire explicit and tacit knowledge while gaining hands-on experience in crucial areas such as product planning, production, logistics, and management processes [17].

The primary aim of LFs is to bridge the gap between academia and industry by providing a practical learning experience to students and professionals and promoting strong collaboration between them [6]. In LFs, individuals can acquire knowledge about the latest industrial technologies and gain hands-on technical experience directly applicable to their careers [16], fostering the development of soft and organisational skills as well [18]. Synergistic approaches to learning are stimulated by collaboration, experimentation and knowledge sharing among students, researchers and industry professionals that develop projects based on LF equipment.

Although the LF term was coined in 1994, the development of widespread initiatives about LF started after introducing the Industry 4.0 paradigm in 2011 [6]. Indeed, LF proved to have an essential role in the development of Industry 4.0, mainly supporting research and technology transfer activities by implementing testbeds and proof-of-concept experiments for testing models, methods and technologies [19]. Prinz et al. [14] report five functional areas of Industry 4.0 that can be employed in LF to train employees about the core competencies of Industry 4.0, such as data processing, autonomy, integration and decentralisation. Tan et al. [20] further demonstrated how learning modules in Industry 4.0 LF support crucial social competencies, such as teamwork, self and time management, adaptability and communication. In the literature, several models have been proposed to classify LF, both supporting the construction of such kind of learning environment (e.g., [21]) and the organisation of research subjects (e.g., [22]). Abele et al. [6] finally proposed a more holistic classification, clustering LF characteristics into seven categories: operating model, purpose and targets, process, setting, product, didactics, and metrics. Other researchers have also used this classification as guidance for the startup of new LF focused on Industry 4.0 [23]. Few studies discuss the adoption of LF in relation to sustainability [24]. More recently, considering the transition towards the Industry 5.0 paradigm, Milisavljevic-Syed et al. [25] proposed an extended classification, including a new dimension concerning sustainability in the broader meaning, including both environmental and social, as well as resilience, thus confirming that LFs are thriving environment to develop learning/training programs and research activities to guide the workers towards the future of industry.

4. The SIF400 Learning Factory at the University of Bergamo

This section contains a detailed description of the SIF400 LF located at the University of Bergamo (Sub-section 4.1) and its classification according to the multi-dimensional classification model developed and validated by the CIRP Collaborative Working Group on LF described in [6, 24] (Sub-section 4.2).

4.1. LF description

The LF installed at the SLIM (Smart Living In Manufacturing) laboratory of the Department of Management, Information and Production Engineering of the University of Bergamo - UNIBG (Italy) includes an assembly, sorting and packaging line consisting of SMC's SIF 400 - Smart Innovative Factory installation, which simulates a smart and connected factory starting from the launch of the production order to the shipment of the finished product. The line consists of 7 stations, which are independent and interconnected with each other in a modular way, performing production, assembly and logistics activities, as represented in Fig. 2.

Fig. 2: The SIF-400 Learning Factory at the UNIBG SLIM Lab

The factory allows the production of a customisable product, ideally represented by containers of different shapes (squared or cylindrical) filled with different coloured (blue, red or yellow) balls and in different quantities, based on the individual stock-keeping unit (SKU) required. The containers are shipped in packs (represented by pallets on which a maximum of four containers are placed). At the client's request, the system produces single or packed containers. The line produces single products from station SIF-401 to station SIF-407, while stations SIF-408 and SIF-409 handle packs of several products. It should also be noted that the line can handle products as make-to-order (stations 401, 402, 405, 407, 408) or as make-to-stock through the use of the single product (SIF-406) and pack (SIF-409) storage station. Finally, the line can be operated via the manual controls on the Human-Machine Interfaces (HMI) provided at each station or via integrated operation controlled by the MES provided on the line: the SIFMES. The line also has an Autonomous Mobile Robot (AMR), OMRON LD-90, which can be called and serve all stations and can be programmed and managed by dedicated software. Even if some production and logistics elements are in the factory in a scaled size (e.g., the autonomous warehouse), the main technologies (e.g., cobot, AMR) are real industrial technologies adopted in real factories. Also, there is an Energy Data Receptor (EDR) device on the line, which monitors individual stations' power consumption and the entire system's pneumatic consumption.

In detail, the stations are composed as follows:

- SIF-401 (Pallet and container feeding station): The function of this station is to feed containers and pallets to the system. The containers can be of two types: cylindrical or quadrangular prisms. The containers are placed on the pallet employing electric actuators and a gravity positioner. All pallets include an RFID tag that allows their identification and traceability throughout the system. Also connected to this station is a SIEMENS Augmented Reality System that allows information about the different components of the station.
- SIF-402 (Container filling station): The containers of solid raw material are filled in this station. The raw material can have different colours (red, blue and yellow) and can be supplied independently or mixed in different doses. Once the containers are filled, the material introduced into the container is checked.
- SIF-405 (Capping station): The corresponding cap is fitted in this station depending on the type of container that arrives. The caps are stored in circular and square section caps in two interchangeable feeders. A pneumatic part type detection system recognises what type of cap is in each feeder. The number of parts in each feeder is known in real-time, thus detecting if either feeder is empty. A machine vision camera verifies that the cap has been fitted in the correct position.
- SIF-406 (Container warehouse station): This station acts as an autonomous warehouse for finished or semi-finished products. It can store 50 containers and their corresponding pallets. Different storage policies could be implemented.
- SIF-407 (Container labelling and dispatching station): This station has a double function: first, it prints QR labels stuck on the containers. They are subsequently inspected using artificial vision and are linked to the RFID of the corresponding pallet. Additionally, the station ships the correctly finished containers for unit product orders.
- SIF-408 (Container packing station): this station links the production and logistics stations. The containers arrive on the transport belt, and a collaborative robot picks them up and places them in a pack in one of the three packing areas in the station. The station has a colour code to indicate each pack's different stages of preparation.
- SIF-409 (Pack warehouse station): this station acts as a warehouse for finished packs. It can store up to 8 packs in its different locations.

At the software level, the line is equipped with:

- HMI (Human Machine Interface) with virtual push-button panel and software for programming and customisation.
- PLC programming software
- MES software for production scheduling (from a Make to Stock or Make to Order perspective), management and control of the system
- Software for the development of the line's Digital Twin

Finally, the line includes a system for Virtual Commissioning equipped with a camera, which provides secure access to various devices with an Ethernet interface (e.g., PLCs, machine vision systems, collaborative robots, HMIs) so that they can be controlled or visualised from anywhere, in real-time, via only an Internet connection.

With this system, a secure remote connection can be made to the SIF-400 system, allowing access to all SIFMES software features and control/monitoring of machine operation. In addition, this system allows Virtual Learning: students can remotely connect to different devices and view the operation of the machine through the IP camera.

4.2. LF classification

To provide a comprehensive perspective on the conception and development of the SIF LF installed at UNIBG, we tried to classify it according to the multi-dimensional classification model developed and validated by the CIRP Collaborative Working Group on LF described in [6, 26], already discussed in Section 3.1. In the following, the seven dimensions are discussed.

- Operating model: the UNIBG LF is operated mainly by the University institution, even if specific target activities can be developed in collaboration with technical vocational schools. Therefore, trainers are usually professors or experienced researchers in the field of engineering. An external supplier has developed the LF, and its purchase has been funded through a Regional Funded Project. Considering the ongoing operation of the FL, the internal University and research group's funding will be used to recruit and support personnel and mid-term projects will be set up to allow a funding continuity. Since the LF is installed in a university laboratory, the courses and learning activities will be developed for free for students (as in a club model, being the students already enrolled in the university degrees).
- Purpose and targets: Main purposes of the LF are education and research. As secondary purposes, vocational training and innovation transfer could be considered, even if they could be pursued in the mid-long term. Thus, the target groups for education and training will be students of bachelor, master and PhD engineering courses, having homogeneous backgrounds and competence levels. The targeted industries are mechanical, automotive and logistics, and learning contents will be developed in the field of production management, automation, cyber-physical systems, HMI, intralogistics design and management. The same topics will be objects of the research activities that will be developed in the LF.
- Process: Following the description in the previous sub-section, the UNIBG LF covers the product/factory lifecycle phases related to manufacturing, assembly and logistics in discrete production. Given the possibility of limited product customisation, the line can support serial or small series production, organised according to a flow manufacturing organisation. The line simulates physical manufacturing activities as joining and filling.
- Setting: The learning environment consists of a physical LF supported by many digital tools, mainly IT after SOP (MES). Nevertheless, digital twin software could be used to perform simulations before SOP. The physical line is life-size, even if it produces small products; therefore, some processes, such as warehousing, are scaled down. The SIF line corresponds to a working system and is modular and reconfigurable in the layout, logistics, and some basic product features.
- Product: The products of the LF are physical containers or packs, as already designed by the line suppliers. They do not have applicability on the market, but they are used for demonstration. The main products are two (containers or packs) with several variants up to 40. The components are always containers, caps, coloured balls and packs. Reusing the components at the end of the line is possible after a manual disassembly activity that must be performed offline.
- Didactics: Didactic activities will be the core of the LF. Learning contents will be developed to enable students to acquire technical and methodological competences, based on the brownfield environment in which open laboratory activities are developed. The LF allows onsite learning and remote connection, supported by a camera that can share an online view of the physical equipment. Trainers could instruct the training but also self-regulated by students, having the trainers play more coaching roles. Both standardised and customised training can be developed in the form of practical lab courses or project work. The students are assumed to have the main knowledge related to production and logistics management as a prerequisite, even if some theoretical foundations about automation and technical aspects could be delivered on demand. Practical exams or oral presentations about laboratory activities are expected to be the most suitable evaluation means to assess learning efficiency.
- Metrics: Since the didactic activities will be delivered to the students attending bachelor and master courses at the University, each training could involve different numbers of participants (from 5 to 50) according to the course. Two or three groups of students could be involved every semester, and the laboratory activities could last around three months. The LF is around 100 sqm.

Based on this description of the UNIBG LF, the learning contents and competencies for Industry 4.0/5.0 are identified and discussed in the following section.

5. Learning contents and competencies enabled by the SIF400 learning factory

As introduced in the methodology, after having analysed the characteristics of the LF and after having classified the LF according to the criteria present in the scientific literature, we moved on to define a framework that identifies the learning contents and the different competencies that can be matured through the LF and from which the different learning modules will be built. In this section, we illustrate how the areas of industrial engineering that can be studied through the LF have been defined and the specific learning contents and competencies that can be matured for each area.

Initially, therefore, in line with what has been described in the previous sections, in particular with the description of the LF developed in section 4.1 and with what has been reported by [20], some areas of industrial engineering, for which some learning contents can be defined that can be learnt through LFs, are identified. The specific learning contents for each area and Industry 5.0 pillar were defined based on the LF user manuals and following a warm-up and use of the LF by a group of 6 persons (2 researchers, 1 PhD Student, 3 Master Students) in order to identify the potential of the LF for learning specific competencies. It was then decided to divide the competencies that can be acquired through specific learning modules based on the use of the LF into technical, methodological, personal, and social competencies. The definition of these competencies was based on the work of Hecklau et al. [27].

Table 1 shows the final version of the framework describing, for each area of industrial engineering, the specific learning contents that can be learnt and the different competencies that can be acquired.

Industrial Engineering Areas	Learning contents	Industry 5.0 area	Technical Competencies	Methodological Competencies	Personal &Social Competencies
Manufacturing	Work design KPIs, Manufacturing processes, Digital Twin	Sustainability, Resilience	Work design and measurements, Control of manufacturing processes through different tools (e.g., electric and pneumatic actuators), Digital Twin implementation and application	Decision-making, Efficiency orientation	Communication Skills, Ability to transfer knowledge, Leadership skills, Sustainable mindset
Assembly	Automatic assembly, Manual disassembly, Work design, Cobot operations	Human-centred design, Sustainability	Supervision and control of automatic assembly, Manual disassembly design and control, Work design and measurements, Design and management of cobot operations	Decision-making, Efficiency orientation	Ability to transfer knowledge
Logistics & SCM	Inventory control, Warehouse, Autonomous Mobile Robots, Material Handling	Sustainability, Resilience	Inventory control management, design and analysis of different warehouse management strategies, Autonomous Mobile Robot management and applications, Material handling management	Entrepreneurial thinking, Decision making, Analytical skills, Efficiency orientation	Networking Skills, Ability to be compromising and cooperative, Sustainable mindset
Maintenance	Corrective Maintenance, Planned Maintenance, Predictive Maintenance,	Resilience	Design, planning and analysis of corrective, planned and predictive maintenance, Definition and analysis of maintenance KPIs	Problem-solving, Analytical skills, Efficiency orientation	Ability to work in a team

	Maintenance KPIs				
Quality	Scraps Management, Quality Control, Control charts	Resilience, Sustainability	Scraps management strategies, Applications of different tools for quality control (e.g., weight control system, camera inspections), Control charts analysis	Problem-solving, Analytical skills, Efficiency orientation	Ability to work in a team, Ability to transfer knowledge
Operations	Order planning, Order Management, Production KPIs, Operations scheduling, MTS and MTO strategies	Sustainability, Resilience	Order planning and management, Analysis of the KPIs linked to the production (e.g., OEE), Analysis of the strategies for the scheduling of the operations, MTS and MTO strategies implementation, Application of the MES software application	Entrepreneurial thinking, Decision making, Analytical skills, Efficiency orientation	Communication Skills, Ability to work in a team, Ability to be compromising and cooperative, Leadership skills, Flexibility
Ergonomics and Human Factors	Human-Machin Interface, Human-Robot collaboration, Augmented Reality	Human-centred design	Human-robot and human-machine collaboration design and management, Augmented reality design and applications	Research skills,	Ability to work in a team
Safety	Human-Robot collaboration, Layout design	Human-centred design	Risks analysis related to the human-robot and human-machine collaboration, Analysis of the layout to avoid risks and make the workplace more comfortable	Problem-solving, Decision making, Research skills	Ability to work in a team, Ability to transfer knowledge, Compliance
Energy Management	Energy consumption, Air consumption, Energy saving strategies	Sustainability	Analysis of the energy and air consumption, Application of energy saving strategies design	Decision-making, Analytical skills, Efficiency orientation	Ability to transfer knowledge, Sustainable mindset
Information Engineering	Database management, Data analysis, Sensor data acquisition, IT applications, Digital Twin	Resilience, Sustainability	Database management strategies, Data analysis tools and strategies, Sensor data acquisition, IT applications (e.g., MES), Digital Twin design and development	Creativity, Analytical skills, Research skills	Ability to work in a team, Ability to be compromising and cooperative, Ability to transfer knowledge, Compliance

Table 1 – LF framework linking Industrial Engineering Areas, Learning contents and Competencies

Table 1 may therefore be a good starting point for defining the different learning modules, which may encompass one or more learning contents depending on the course to be delivered and the target participants in the lessons, including also other participants different from bachelor and master students (e.g., VET participants, practitioners).

6. Discussion and conclusion

The purpose of the research presented in this paper was to identify the learning contents and related competences (RQ2) that can be acquired exploring the different potential research and teaching path for the different areas of industrial engineering in Industry 5.0 based on the analysis of a LF (RQ1).

Thanks to what already exists in the scientific literature, especially regarding the classification of LFs and following the process we have illustrated, it is possible to derive the possible learning contents available based on the processes and technologies present in the different stations of the LF. However, the correct and complete identification of the learning contents that can be delivered using the LF in the courses was not a quick and easy task as it required an in-depth knowledge of the different stations that can only be acquired through a long period of use and warm-up of the laboratory. Furthermore, it could be seen that for some areas, such as logistics and operations, multiple learning contents are available that will allow the development of different use cases and teaching modules, while for other areas such as energy management and safety the learning uses will be reasonably more limited. It should also be emphasized that for some areas such as Information Engineering, to develop modules and courses that take into account the identified learning contents, it will be necessary to involve teachers and researchers with skills more closely related to the areas of Computer Science and Data Analytics, as the complexity of the elements involved goes beyond the skills of an industrial engineer.

Considering the Industry 5.0 pillars, it can be observed that the LFs could support the development of learning contents that concern a well-balance overview over the aspects related to sustainability, resilience and human-centred design.

The presented research has several limitations that need to be acknowledged. Firstly, the study focused on the analysis of a single LF with specific characteristics, which limits the generalizability of the findings. Therefore, future research should aim to replicate the study using different LFs with various characteristics to ensure the validity of the results.

Despite these limitations, this research is a crucial first step towards developing methods that support companies, researchers, and teachers in identifying the learning contents and competencies that can be acquired through LFs. Educational support tools such as LFs can play a significant role in improving student learning outcomes and enhancing their skills. Thus, it is imperative to identify the benefits and possibilities of these tools to promote their use in educational settings.

In conclusion, while this research has limitations, it provides valuable insights into the potential of LFs as educational support tools. Further research should aim to build on these findings and develop more comprehensive approaches and learning modules to support student learning and skill development.

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