Received: 20 May 2024 | Accepted: 17 July 2025

DOI: 10.1111/dsji.70015

DECISION SCIENCES
JOURNAL OF INNOVATIVE EDUCATION

TEACHING BRIEF

# Learning factory in logistics: Evaluation of the effects of a hands-on experience for automated warehouse processes

**Andrea Ferrari** | **Anna Corinna Cagliano** | **Giovanni Zenezini** | **Antonio Carlin** | **Giulio Mangano**

Department of Management and Production Engineering, Politecnico di Torino, Torino, Italy

**Correspondence**
Andrea Ferrari, Department of Management and Production Engineering, Politecnico di Torino, Torino, Italy.
Email: andrea.ferrari@polito.it

**Abstract**

In recent years, automated warehouses have become increasingly important to meet the rising demand of supply chain operations. Despite their growing relevance to industry, these systems remain largely underrepresented in academic settings, which contributes to a significant gap in student knowledge and preparedness. Traditional educational approaches often fail to equip future professionals with the practical skills required by modern logistics systems. While the learning factory paradigm partially addresses this gap, it typically places limited emphasis on logistics processes. To bridge this divide between theory and industrial practice, a hands-on learning experience was conducted in a logistics-focused learning factory involving Bachelor's and Master's engineering students. A structured questionnaire was administered to evaluate students' perceptions of automated warehouses, and statistical methods were employed to analyze both the short- and medium-term impacts of the experience. Findings revealed a strong interest among students in industrial logistics, despite limited prior exposure to automation technologies. Consistent with previous research, the hands-on approach was particularly effective for Master's students, highlighting its potential as a valuable educational tool in logistics engineering.

**KEYWORDS**

automated warehouses, engineering students, hands-on experience, learning factory, statistical analysis, university

## 1 | INTRODUCTION

Automated warehouses play a key role in defining and supporting modern logistics processes (Marolt et al., 2022; Schenone et al., 2020) and are widely adopted in various industrial sectors, including manufacturing, logistics, large-scale distribution, e-commerce, and healthcare. Automation may involve storage and retrieval operations, as well as the material handling within a facility. Automated storage and retrieval systems (AS/RSs) represent one of the most effective solutions for storing and retrieving unit loads (ULs) without human intervention (Ferrari & Mangano, 2023; Hoshimov et al., 2024). Regarding material handling, the ULs movements can be allocated to transportation systems called automated guided vehicles (AGVs). One of the most recent and advanced types of AGVs developed is the autonomous mobile robot (AMR), which is capable of moving autonomously along a non-predefined route by planning a collision-free path from a starting point to a target destination (Li et al., 2022).

Designing and managing these automated logistics systems requires both managerial and operational staff with the appropriate skills. However, companies nowadays struggle to find professional figures who fit their needs with regard to logistics processes and particularly warehousing implementations (Arvis et al., 2016; Lin & Chang, 2018). Despite the strengths of engineering faculties in mediating scientific knowledge, students often struggle to transfer this knowledge in a constantly changing professional environment (Pittich et al., 2020). This situation is also reflected in the wider field of engineering education, where teaching methods based on environments reproducing real-world applications are limited (Salinas-Navarro et al., 2020). Furthermore, automated warehouses often present additional challenges in terms of human-machine interaction compared to traditional warehouse equipment, changing the educational requirements for industrial professionals. To ensure efficient and collaborative internal and external material flows, workers must now be equipped with new technical and operational competencies (Woschank & Pacher, 2020a).

As a consequence, innovative teaching methods that bring the learning process closer to industrial practice and enhance the skills of young engineers are needed in conjunction with traditional ones (Gento et al., 2021; Woschank & Pacher, 2020b). As such, engineering education might benefit from increased adoption of active learning strategies involving practical applications. Among them, hands-on experiences have recently gained momentum, especially in the field of industrial logistics (Kinzli et al., 2018; Schmuck, 2021; Woschank & Pacher, 2020c). These educational approaches aim to emulate real situations to support positive experiences that could lead to psychological responses or desired behavioral outcomes, such as motivation and engagement (Klock et al., 2021). In addition, the interest fostered in students by hands-on experiences is positively correlated with their learning performance (Guimarães & Lima, 2021). The relevance of hands-on experiences in engineering education has long been discussed in the literature as a fundamental means of developing judgment capabilities and appropriate skills in future engineers, beginning with undergraduate students (Abdulwahed & Nagy, 2009; Chadha & Hellgardt, 2023). In addition, research shows that people tend to learn and retain knowledge more effectively through experiential learning (Oke et al., 2024). In this context, there is a scarcity of studies investigating the impacts of hands-on experience from the point of view of the participants. Hands-on experiences are often provided in the context of a learning factory (LF) (Larsen et al., 2019). LFs, which originated in the United States in the manufacturing sector more than 30 years ago and have recently been introduced in Europe, can be defined as training and education environments wherein both students and professionals actively apply theoretical knowledge under supervision to tackle real challenges within a setting that simulates industrial conditions (Bellucci et al., 2022; Weidig et al., 2014). However, only few LF experiences focus on logistics processes, and those that do tend to concentrate primarily on inventory management rather than on material handling operations (Vailati et al., 2023).

The present work discusses a hands-on experience carried out in a logistics LF that involved both Bachelor's and Master's engineering students. In particular, the proposed research aims to answer the following research questions (RQs):

- RQ1: What is the perspective of engineering students on the proposed hands-on experience focused on automated warehouses?
- RQ2: What impact does the hands-on experience have on the achievement of learning objectives (LOs) by the students?

At the end of the experience, a questionnaire was administered to assess the students' level of awareness and interest in automated warehouses and logistics processes. Furthermore, the effect of the proposed hands-on experience on the students' learning process was analyzed through a logistic regression analysis, with the exam score serving as the dependent variable.

The remainder of this article is structured as follows. The next section presents an overview of the most relevant hands-on experiences and LFs carried out in industrial contexts, as well as the innovative teaching methods aimed at providing insights regarding warehouse logistics. Next, the description of the proposed hands-on experience is provided, followed by a discussion of the main outcomes and results of this study. Finally, conclusions are drawn in the last section of the article.

## 2 | LITERATURE REVIEW

### 2.1 | Hands-on experiences and learning factories in industrial contexts

Hands-on experiences as a teaching method have already been adopted in several industrial contexts, mainly in manufacturing and operations management courses (Hamzeh et al., 2017). Wilson (2018) devised a hands-on experience that mimicked a production process that improved the ability of undergraduate students to analyze and apply a few theoretical concepts, arguing therefore that hands-on experiences can satisfy different stages of the learning process. Stuart (2014) tested whether blending a traditional teaching method with a student-centered learning approach would alter the way students operate in a manufacturing environment and would enhance their safety culture. Undergraduate students were challenged with a series of manufacturing tasks using reusable objects in a laboratory environment. This approach was found to foster the safety culture more effectively than traditional teaching methods. Nevertheless, students with prior industry and machining experience found the practical labs the most constructive of all the approaches. Several of the hands-on experiences available in the literature have been carried out in LFs. LFs are environments generally developed by universities to improve the educational experience of participants in one or multiple areas of expertise. These infrastructures, comprising quite expensive manufacturing equipment, are usually funded by either national or international institutions interested in advancing science and education. Examples of such institutions include the National Science Foundation in the United States, which awarded a consortium of universities a grant to develop one of the first LFs (Abele et al., 2015), and the European Commission (Weidig et al., 2014). In addition, companies may be interested in co- funding academic LFs as a means of promoting their collaboration with universities and connecting with future professionals who can add value to their organizations. For instance, the University of Valladolid and Renault Nissan Consulting collaborated to create an LF aimed at providing training in lean manufacturing (Redondo et al., 2022). Also, the Bavarian network of LFs for energy-efficient production is a joint project between local universities and companies (Kreitlein et al., 2015). However, it should be acknowledged that various interconnected factors may sometimes limit the ability of academic institutions to obtain adequate public funding and private support for creating LFs. These factors include competition for financial resources, institutional regulations, and the economic conditions affecting both the education and business sectors. Such a scenario results in disparities in access to essential resources, which are crucial for establishing and maintaining these innovative educational environments and might hinder the widespread development of LFs (Quinn et al., 2022).

Among the success stories documented in the literature, De Vin and Jacobsson (2017) developed a LF to emulate a manufacturing environment. In this case, the authors involved only actual workers and did not provide indications on the impact of such teaching methods on learners, but rather proposed a series of hypotheses for future research. Similar to this work, most of the contributions available in the literature merely discuss the structure and objectives of a LF, without assessing the impact on learners of the activities that can be performed within it. Among them, Muschard and Seliger (2015) described the physical facilities of an LF intended for professional training where products from recycled plastic materials are manufactured. In the same year, Faller and Feldmúller (2015) presented a LF replicating a complete company, intended to improve the operational and managerial knowledge and skills of both university students and professionals. In recent years, Somaskantha Iyer et al. (2023) converted a traditional manufacturing lab into an Industry 4.0 LF by digitally connecting machines via IoT to obtain a flexible manufacturing system. In this LF, material handling is carried out by AGVs. Some LFs not only rely on physical infrastructures but also have a virtual counterpart. Rasovska et al. (2022) presented the FleXtory LF, where manufacturing processes are emulated by means of production and assembly lines complemented by warehouse areas. The LF also adopts advanced technological solutions, such as AGVs, AMRs, and cobots. Additionally, the LF is enhanced by a digital twin. The physical and digital structures of an LF, as well as the learning benefits their integration can bring to university students, are also addressed by Zarte et al. (2019). Nevertheless, hands-on experiences can be performed in LFs that are virtual only. In this realm, Weidig et al. (2014) created a virtual LF based on the digital model of a factory, while Lang et al. (2018) developed a modular digital LF where students and researchers can design and assess different factory layouts also integrating Industry 4.0 technologies.

However, several authors also assess the effectiveness and impacts on learners of performing hands-on experiences. Santos et al. (2012) conducted a survey to obtain feedback from undergraduate students involved in a hands-on experience reproducing assembly operations. Most of the students gave positive assessments of the activity due to its ability to stimulate teamwork. Angrisani et al. (2020) proposed some hands-on experiences as part of an Industry 4.0 undergraduate course. They mixed hands-on experiences where students had to design and develop a project prototype with cooperative project-based learning and scenario-based learning to develop new skills such as adaptability, teamwork, entrepreneurship, and problem-solving. Again, students agreed on the effectiveness of the experience in achieving the expected goals. Nikandish et al. (2023) described a hands-on experience based on a process observation exercise and found that it positively impacted students' knowledge acquisition by measuring the students' performance on a mid-term exam.

This literature suggests that hands-on experiences can be very effective in achieving several goals, provided that they are fine-tuned to the goal at hand. Furthermore, students with previous work experience are found to be more receptive to hands-on experiences due to the tacit practical knowledge they have accumulated. Additionally, LFs appear to be a widely debated topic in manufacturing, but there is a lack of focus on the effects the use of their physical and digital facilities might have on learners.

## 2.2 | Innovative teaching methods in warehouse logistics

As previously mentioned, hands-on experiences have been largely applied to manufacturing processes. However, their diffusion in logistics, and in particular warehouse settings, remains scarce. Nevertheless, there have been some attempts at introducing innovative, action learning based teaching methods in warehouse logistics contexts. The available literature can be subsumed into two groups: those addressing innovative teaching approaches about warehouse design and building, and those related to operational activities.

In particular, the first group relies primarily on simulations and games. For example, the work by May (2021) describes a learning experience based on the combined use of Virtual Reality (VR) and the FlexSim software tool for simulations. Undergraduate students were engaged in the design of a new warehouse. An assessment questionnaire was administered both before and after the experience, and basic descriptive statistics were calculated. This study demonstrated that the learning commitment, the problem-solving ability, and the self-confidence of students increased after participating in this practical experience. In another study, Vodenicharova et al. (2022) examined the project management effort underpinning the construction of a new warehouse and developed a logistics project management game intended for both university undergraduate and graduate students, as well as professionals. The game's purpose was to build a warehouse in the shortest possible time and at the lowest total cost. Also in this case, participants completed a questionnaire both before and after the experience. Indicators about the success degree were calculated, and a cluster analysis was performed to group the participants into categories based on the acquired knowledge, motivation, confidence, and teamwork ability. In a similar vein, Bergström et al. (2020) proposed a game to support group discussion and cooperation on construction logistics setups. The objective was to identify potential issues when developing construction logistics setups, together with supporting the interaction among the supply chain actors involved. Finally, the hands-on experience put forward by Benaragama and Koomsap (2020) simulated active learning in the design of automated material handling equipment. A fleet of AGVs was designed with the possibility of acquiring skills also about fleet management and navigation.

The second group of innovative teaching methods, focused on warehouse operational activities, is often developed in dedicated laboratories. One example is the Supply Chain Management Technology Laboratory described by Scott et al. (2007), where students from undergraduate and advanced industrial distribution courses can take advantage of conveyors, racking systems, tracking technologies, and warehouse management software systems to simulate receiving, storage, order fulfillment, and shipping functions. The need to apply the notions discussed during class to be successful in the laboratory experience encouraged students to become more involved in them. When a laboratory environment with logistics equipment is not available, VR can also be valuable to simulate warehouse operations. In such a context, Schlüter and Kretschmer (2020) proposed a serious game based on VR to make warehouse trainees and professionals explore ergonomics issues in human-machine interfaces in intralogistics activities. Questionnaires and interviews were administered to participants to assess the effectiveness, usefulness, and ease of the experience. The associated outcomes were analyzed by means of descriptive statistics. Finally, Ayuby et al. (2020) developed a hands-on experience that addresses not only logistics systems design but also the related distribution activities and the evaluation of the associated costs. By testing it with students of five logistics and supply chain university courses, they concluded that a significant correlation exists between students' learning and performing the experience. The limited hands-on experiences in logistics are accompanied by a lack of LFs specifically focused on such a field. However, it has to be recognized that the attempts to develop LFs about logistics processes have been increasing in the last few years (Kolesnyk et al., 2021). In particular, automated warehouse systems and AGVs are implemented to help optimize both storage and material handling activities (Milisavljevic-Syed et al., 2023).

## 2.3 | Research gap and contribution

A review of the literature reveals that, although hands-on experiences have been used as a teaching method in manufacturing or operations management courses, their diffusion in warehouse logistics is currently limited, not well-structured, and not well-established. In particular, there is a need for hands-on experiences focused on operations in automated warehouses targeting undergraduate and graduate students, so that future engineers and managers can effectively become aware of the actual potential, advantages, and disadvantages of the alternative storage and material handling solutions available on the market. This will allow them to perform more informed and aware decision-making in their future professional activities.

Also, among the available contributions, some assess the perception of the participants about the characteristics of the logistics equipment and systems constituting the core of the hands-on experience, while others evaluate the perception of carrying out the experience itself. In most cases, a questionnaire is administered before and after performing the experience, although the associated outcomes are usually analyzed with qualitative and descriptive statistics and not by means of structured quantitative statistical techniques (Nikolic et al., 2021). The use of such quantitative approaches would be highly beneficial to assess the short-term effectiveness of innovative academic teaching methods (Culver et al., 2022). Moreover, the medium-term impact on students taking part in hands-on experiences about warehouse logistics (assessed, for example, through final exam scores) is not studied, since the literature focuses more on the short-term benefits that can be achieved directly after performing the experience. Thus, there is no assessment of how hands-on experiences help students master logistics topics acquired during university courses in the medium run. However, learning processes that require an active involvement of students in practical experiences, aimed at making them reflect on the knowledge developed during lectures, might increase the students' academic performances (Menekse, 2020). Also, the knowledge retained will guide professionals in choosing the best automated warehouse configurations based on a company's business needs.

Therefore, the present research proposes a newly designed hands-on experience where university engineering students operate an automated warehouse hosting small-sized ULs in a logistics LF environment and perform receiving, storing, picking, kitting, and delivery activities. The short-term impact of the experience on students was assessed through a post-questionnaire, and the results were empirically analyzed; the medium-term impacts were evaluated via logistic regression analysis by comparing the final exam scores of those who took part in the experience with those of those who did not. In such a way, both task-level achievement goals and course-level grades are addressed. This contribution also aims to support the development of logistics LFs, not only by

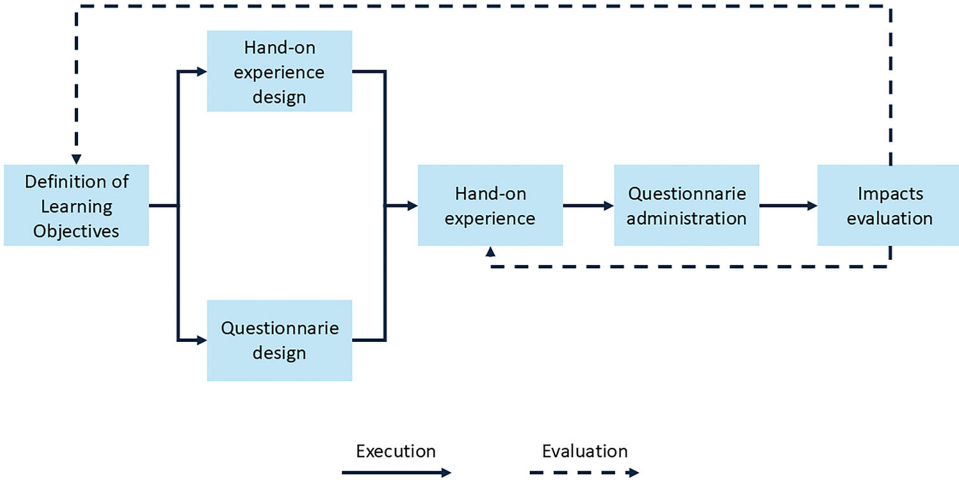



**FIGURE 1** Research approach.

presenting the facility, but also by analysing how learners can benefit from the associated teaching activities.

## 3 | RESEARCH APPROACH

This study describes a hands-on experience involving the replication of the main operations of a distribution center within a university warehouse LF. This section describes the research approach followed in this article and is shown in Figure 1. Therefore, a discussion of the LOs of the courses in which the experience was proposed, an analysis of the environment where it was carried out, and an explanation of the required activities are included here. Moreover, the definition of how the hands-on experience integrates with the course LOs is proposed, followed by a description of the questionnaire administered to the students. Before the experience, a pilot version of the questionnaire was sent to the Internal University Review Board for approval, to ensure inclusive language and fair content. Next, the statistical approaches used to evaluate both short- and medium-term impacts of the hands-on experience are described, as well as how the hands-on experience was perceived by the participants and how the LOs were met.

### 3.1 | Learning objectives

Both Bachelor's and Master's students were involved in the hands-on experience. In particular, Bachelor's students were at- tending their third year of the Production and Logistics Engineering Program that helps students develop knowledge about the main production processes and managerial relationships with both customers and suppliers. Within such a program, the Industrial Plant course is intended to provide students with the most relevant methodologies for designing and managing a production plant, in terms of general layout, machinery, warehouse systems, auxiliary services, and physical flows. These LOs are outlined in Table 1 and have been defined according to the revised Bloom's taxonomy (Anderson & Krathwohl, 2001). The LOs marked with a star symbol in Table 1 represent those that the hands-on experience contributes to achieving.

The course also includes a project work wherein students work in teams of eight, focused on sketching the plant layout of an industrial facility, including production areas, plant support functions, and warehouses. As part of the project work, storage systems are selected and appropriate material handling equipment is identified. The project work grade constitutes 25% of the final exam mark. Students earn the remaining 75% of the grade by completing a written exam test made of both open-ended and closed-ended questions. Answering these questions might require developing a description of the theoretical topics discussed during lectures, as well as solving numerical problems and case studies based on the knowledge acquired during both lectures and project work classes. The questions are related to the design of an industrial facility, including describing the characteristics and the performance of automated storage and material handling systems, choosing their most appropriate types, and performing a preliminary sizing of these systems according to given warehouse requirements. Additionally, students might be asked to discuss the characteristics and the performance of the available approaches and technologies to perform picking in warehouses. Thus, such a course fulfills some of the LOs and skills advocated by the literature on logistics engineering education, related to warehouses and both traditional and automated methods for storage and material handling systems (Lutz & Birou, 2013; Wagner et al., 2020; Woschank & Pacher, 2020c; Wu et al., 2004). The hands-on experience was proposed to undergraduate students in the second half of the semester, after the topic of automated warehouses had been explained in class.

Graduate students were attending the second year of the Master's program in Automotive Engineering. This program provides the main basis for the design of a vehicle (with the

**TABLE 1** Courses learning objectives.

| Bachelor's course | Master's course |
|---|---|
| Describe the steps of industrial plant design | Analyze the applications of the Industry 4.0 technologies to warehouse design |
| Compare the plant layout types | Compare the main types of warehouse layout |
| Select the best plant layout solution based on existing technological, logistics, regulatory, and economic constraints | Evaluate the available automated solutions for material handling and storage equipment * |
| Compare the material handling and storage equipment currently available | Plan the main warehouse operational activities (e.g., picking, sorting, pack-aging, etc.) by means of the latest Industry 4.0 technologies * |
| Indicate the main automated solutions for material handling and storage equipment * | Design the complete layout of an automated warehouse |
| Indicate the main safety measures to be adopted in workplaces Sketch the complete plant layout of an industrial facility | |

*Note*: The learning objectives marked with * represent those that are achieved through the hands-on experience.

most important related components) and the relevant methodologies for the proper management of production processes. Within this program, the Industry 4.0 for Production Systems (I4.0 PS) course examines the methodologies for the management of the processes within a manufacturing facility, with emphasis on the available recent technologies. It consists of two parts that are developed concurrently during the semester. Part A is dedicated to analysing the evolution of production systems, from their origins in the Ford factory to the latest innovations of the Toyota Production System and Lean Manufacturing, as well as the Industrial Internet of Things. Part B focuses on warehouse design, storage, and material handling, with particular emphasis on automated and digital systems such as AS/RSs, AGVs, and VR. This hands-on experience was introduced into Part B of the course. The key LOs of I4.0 PS Part B are described in Table 1. Additionally, students are required to work in teams of five members to develop a project for the design of the complete layout of an automated warehouse for the storage of parts in the automotive sector. This project represents 50% of the examination; the remaining exam portion is based on a written test containing both quantitative exercises and open-ended questions. Here, students might be required to assess the characteristics of different automated material handling and storage solutions for specific warehouse case studies, size these systems, and develop warehouse layouts. Additionally, they might be asked to plan warehouse operational activities, such as picking, sorting, and packaging, by choosing appropriate digital supporting technologies according to the given situation. Also in this case, the course LOs are in line with those characterizing the logistics engineering education.

Both courses, therefore, provide a practical experience that simulates real warehousing processes—an approach that seems to more effectively achieve the LOs. In fact, although the specific goals of a hands-on experience can vary widely, a key objective is to support a better understanding of the relationships between theoretical models and the reality that these models represent. Consequently, if students are able to understand a model at a deep level, and particularly its relationship to reality, then their ability to use that model to reason about actual situations will be enhanced (Machet et al., 2012).

## 3.2 | Hands-on experience in a warehouse learning factory

### 3.2.1 | The learning factory infrastructure

The hands-on experience was carried out in a university LF where various logistics and digital technologies are installed. The proposed LF was financed by a national funding scheme. Based on a national selection process, the Department of Management and Production Engineering (DIGEP) was included in the list of "Departments of Excellence" at Politecnico di Torino. The evaluation was carried out by a committee of the National Agency for the Valuation of the University and Research System (ANVUR). The funds, as foreseen by the projects presented and approved by the Ministry of Education, University and Research (MIUR), were intended to strengthen human capital, research infrastructures, teaching and research activities. The funding received by the department was assigned to various DIGEP research groups for promoting integration between multiple disciplines.

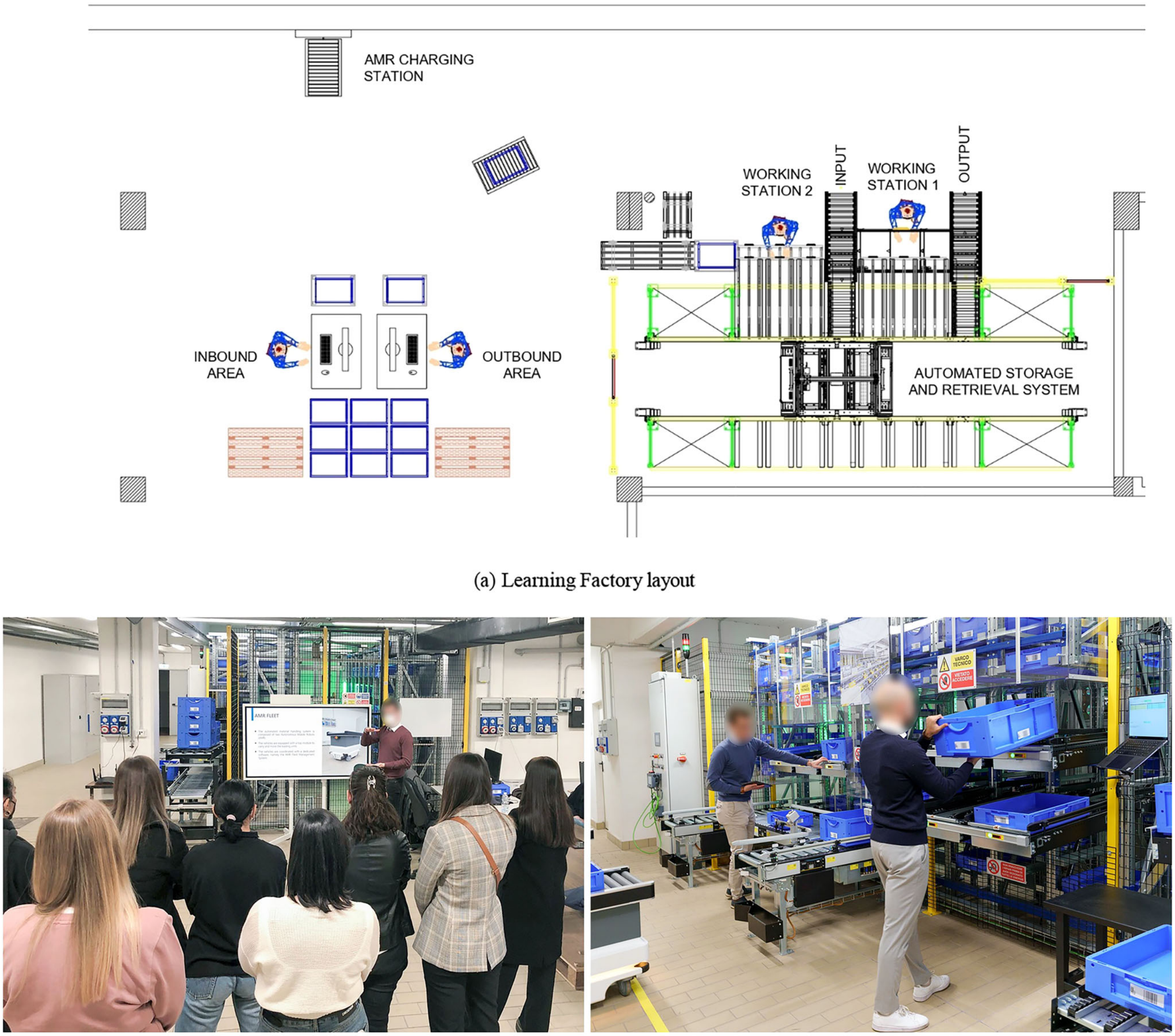
The research group affiliated with the authors of this study decided to implement a small automated warehouse consisting of an AS/RS and a fleet of AMRs as material handling technology. The AS/RS is made up of:

- A multilevel shuttle (MLS) aisle-captive system similar to a mini-load stacker crane, able to move totes, trays, or boxes using single, double, and multiple commands;
- A single-aisle storage rack with seven tiers and eight columns, with single, double, and multiple depth storage locations;
- An input/output roller conveyor system;
- Two working stations installed within the storage rack with pick-to-light gravity flow racks for parts-to-picker operations.

The AS/RS is supported by a warehouse management system (WMS), and a warehouse control system (WCS). The former is a software application that helps organizations effectively manage and control their warehouse operations. It provides real-time visibility of inventory, automates various

DECISION SCIENCES JOURNAL OF INNOVATIVE EDUCATION






(a) Learning Factory layout

(b) Hands-on experience introduction

(c) Hands-on experience execution

**FIGURE 2** Warehouse learning factory.

warehouse processes, and facilitates the efficient movement and storage of goods within the warehouse (Ferrari et al., 2024b). The latter is a software application that directs the real-time activities of the AS/RS (Ferrari et al., 2024a).

The material handling operations are carried out by a fleet of two AMRs, one of the most advanced technologies for ware- house material handling, thanks to their open-path navigation system. The activities of the two robots are controlled by a fleet management system (FMS), whose role is to optimize internal transport by prioritizing and selecting the most appropriate vehicle for each task (Srinivas & Yu, 2022). Figure 2a shows the layout of the warehouse LF areas.

The automated warehouse installed in the university's LF and demonstrated during the hands-on experience is much smaller than a real automated warehouse. As a result, its performance (e.g., cycle time, throughput) cannot be compared with the one of a real system. However, the warehouse in this study makes it possible to emulate and show the students the operational processes of a real warehouse. Therefore, through the proposed experience, the students were able to experience the main activities required in automated warehouse operations, making it possible to expose students to a near-real operating system and, in turn, assess their level of awareness of automated warehouses.

### 3.2.2 | The hands-on experience design

The hands-on experience consisted in reproducing the main warehouse operations of a fictitious company called NewTech operating in the e-commerce sector. Such a sector is selected since students are quite familiar with it as final consumers (Samuel & Anita, 2023).

Specifically, NewTech distributes a set of devices and accessories, namely smartphones and smartphone covers of two different brands. In addition, NewTech delivers to customers who purchased a smartphone together with a cover of the same brand a gift kit containing a USB flash drive and a set of earphones. The company operates as a distribution center, where several processes are completed. The inbound process includes the management of goods coming from the company's suppliers. When they arrive at the warehouse, they are accepted and inserted into empty totes. The association between a specific UL and the products is registered by the operator in the WMS. Then, the operator recalls an AMR by using the FMS. The software selects the first available vehicle, which moves toward the inbound station. When the vehicle arrives to the required position, the tote with the goods is manually loaded onto it. Then, the UL is transported to the AS/RS, where it is moved by the conveyor to the interface point with the MLS. At that point, the WCS autonomously selects a storage location and generates storage missions for the handling device.

Another process carried out in the NewTech distribution center is the kitting. In general terms, the kitting task can be referred to as the procedure of grouping together all the materials and components needed to make a product (Ferrari et al., 2022b). In NewTech, working station 1 is associated with the preparation of gift kits (Figure 2a). They are created in advance and stored in the warehouse to ensure a continuous supply when they are needed to complete customer orders. A gravity flow rack pick-to-light system is installed in the station to facilitate the operator in carrying out the process. At the kitting order launching, the MLS retrieves an empty tote that will contain the gift kit once the operation is completed. The UL is automatically moved in front of the operator by the conveyor system. Meanwhile, the WCS generates the retrieval missions for the components of the kits, namely the USB flash drive and earphones. The totes containing these items are transferred by the MLS to the gravity flow racks. When they arrive, the pick-to-light system turns on and it indicates the product quantities to get from each UL to the operator. The worker puts the products into the empty tote, which is then transported by the motorized conveyor toward the MLS.

In working station 2 (Figure 2a), the warehouse workers carry out picking operations by retrieving smartphones and covers according to customer orders. This process is similar to kitting, except for two aspects. First, the empty tote is not automatically brought in front of the operator, but it is taken manually from a feeding buffer near the station. Second, after picking completion, the tote is loaded onto an AMR previously called by the worker and not stored within the racks.

Finally, the shipment ULs with the customer orders are automatically moved by the AMR to the outbound station. There, another operator unloads the tote and places the products into a cardboard box. Afterward, the box is loaded on a pallet waiting to be shipped to the final customer. If the customer order requires a gift kit, this is automatically retrieved from the warehouse by the MLS. Then, it is handled by the output conveyor, and afterward it is transferred to the outbound station by another AMR. Lastly, the operator declares the order to be closed by using the WMS.

Ten sessions of the hands-on experience were conducted with groups of six to eight students each, composed of either undergraduate or graduate students. The proposed hands-on experience was organized in extra time slots. A total of 62 students participated in the experience on a voluntary basis: 48 Bachelor's students and 14 Master's students. The course of the undergraduate program is compulsory; thus, all the students enrolled (286) must attend the course. On the contrary, the Master's course is elective and therefore only a subsample of graduate students attend the course (28). This led to a disparity in terms of the number of students involved. To better engage the students and make the experience more realistic, the students were asked to provide their smartphones and covers. Each session lasted around 1.5 h and consisted of four phases. During the first one, the experience was described by the lecturer, followed by a demonstration of how each single warehouse process needed to be carried out (Figure 2b). In the second phase, inbound (3/4 students) and kitting (3/4 students) operations were conducted simultaneously by the students. During the third phase, picking (3/4 students) and outbound (3/4 students) tasks were performed (Figure 2c). Since the kitting and picking activities are very similar, students in charge of kitting in the first phase of the experience were then assigned to outbound in the second phase. By contrast, the students working on inbound during the first part of the experience were assigned with picking during the second part. The final phase was dedicated to the filling in of the questionnaire by the students.

The aim of the hands-on experience is to achieve some of the LOs of the Bachelor's and Master's courses described in Section 3.1. First and foremost, the experience aims to increase the students' knowledge of the existing automated storage and material handling equipment. Moreover, it supports Master's students to plan warehouse operational activities, such as order processing and picking, as well as the associated information flows by means of the latest Industry 4.0 technologies. These elements are all part of the relevant logistics engineering LOs as recognized by literature (Naim et al., 2000; Wagner et al., 2020; Woschank & Pacher, 2020c). By switching roles between the second and third phases of the experience, each student was able to see and be involved in different aspects of warehouse operations. Through the proposed hands-on experience, the undergraduate students were expected to corroborate one of the course LOs, namely, indicating the main automated material handling and storage equipment solutions available on the market, by also gaining insight into how a warehouse operator should interact with them. Similarly, the hands-on experience was proposed to graduate students to foster the achievement of two LOs of the course, namely evaluating automated material handling and storage systems and planning warehouse operations with Industry 4.0 technologies. In addition, the use of the WMS and FMS also provided an insight into an example of advanced digital systems.

## 3.3 | Impact assessment

The short-term impacts of the hands-on experience were assessed based on the students' perceptions of the experience, as well as their increased awareness of the topic. Then, the medium-term impacts of the experience were measured on students' grades at the end of the course.

### 3.3.1 | Short-term impact

At the end of each hands-on experience session, a questionnaire was administered to the students who took part in that session. All questions included were closed-ended ones, divided into multiple-choice questions and evaluation questions modulated on a 5-point Likert scale, where grade 1 represents total disagreement and grade 5 represents total agreement. This scale was selected because it is widely used in education and social science research (Joshi et al., 2015). The questionnaire was submitted at the end of the hands-on experience through a Google Form.

The survey was divided into three sections. The first one was intended to frame the students based on a set of demographic questions related to their level of education, personal interests in industrial logistics, previous working experience in industrial sectors, and prior knowledge of automated warehouses. Moreover, the level of interest in logistics and the experience were asked to understand if the participants who decided to take part in the proposed logistics experience were already interested in better understanding the organization of internal logistics processes. Then, the extent to which the hands-on experience modified their interest toward automated warehouses and their willingness to work in logistics was assessed.

The second part focused on the hands-on experience. Particularly, the student's role during the test was traced, as well as general impressions about the experience and the improvement of knowledge on the involved systems. Furthermore, the level of difficulty of the experience was asked, together with the perceived level of difficulty of an AS/RS.

The third section is intended to measure how students estimate the impacts of the implementation of automated warehouses. For this reason, they were asked to assess the effectiveness of having AMRs supporting automated warehouse operations. Next, respondents were asked to rank the impacts of the use of an automated warehouse on a list of key performance indicators (KPIs). In particular, put-away time was taken into account, since it is one of the most costly activities in warehouses (Öztürkog˘lu, 2020). Storage and retrieval cycle time was also included because it can be significantly reduced by using automated warehouses (Ferrari et al., 2022c). Similarly, the number of errors committed might decrease by exploiting automation (Atieh et al., 2016). In addition, since automation allows for higher throughput in terms of ULs moved in a specific time span (Lerher et al., 2021), this issue was considered in the questionnaire. The perceived impact on the required amount of floor area was included in the questionnaire because the adoption of automated storage systems might result in a better usage of the floor space (Ekren, 2020). Moreover, students were asked to evaluate how automation can affect the work pace and how warehouse operators may have difficulties in keeping up with their work. Furthermore, since stress plays a role in work environments, students were also asked to indicate the level of stress for an operator working in an automated warehouse (David et al., 2008). Finally, another impact for warehouse operators might be related to the enhancement of their skills for running automated warehouse activities (Shah, 2021).

To investigate the different perceptions of Bachelor's and Master's engineering students who took part in the experience, responses to the questionnaire were quantitatively analyzed using the Kruskal–Wallis (KW) test, a non-parametric test for not normally distributed data, limited sample size, and ordinal responses (Rosano et al., 2022). The null hypothesis of the test assumes that the samples come from the same population with equal medians. Rejecting the null hypothesis indicates a significant difference in medians among the subgroups, meaning that at least one group has a different perception about a specific issue (Zenezini et al., 2022).

### 3.3.2 | Medium-term impact

As the course LOs related to hands-on experience were tested via open- and closed-ended questions in the final exam, the medium-term impacts of this experience were evaluated by investigating participants' performance in the exam. Thus, two ordinal logistic regression (OLR) models for Bachelor's and Master's engineering students were built. OLR is a statistical approach useful to model the connection between a set of independent predictors and an ordinal response (Harrell, 2015). To determine whether the association between the response and each predictor in the model is statistically significant, it is necessary to compare the *p*-value of the predictor with the selected significance level (Ferrari et al., 2022a). Then, the effects of each predictor on the nominal response can be analyzed through coefficients and odds ratios (Montgomery, 2017).

# 4 | DISCUSSION OF RESULTS

## 4.1 | Short-term impact

Questionnaire responses revealed that 90% of the people in the sample never worked in companies operating in industrial or logistics sectors. Moreover, only 35% saw an AS/RS

**TABLE 2** Frequency of responses on perceived impacts.

| | Likert scale values | | | | |
|---|---|---|---|---|---|
| **Impact** | **1** | **2** | **3** | **4** | **5** |
| Put-away and inbound time | 0 | 2 | 4 | 39 | 17 |
| Storage and retrieval time | 1 | 2 | 7 | 27 | 25 |
| Number of errors | 3 | 1 | 4 | 27 | 27 |
| Throughput | 2 | 0 | 5 | 27 | 28 |
| Covered area | 0 | 4 | 15 | 22 | 21 |
| Operator fatigue | 2 | 1 | 5 | 18 | 36 |
| Operator skillset | 6 | 8 | 12 | 27 | 9 |
| Work simplification | 0 | 2 | 6 | 33 | 21 |

*Note*: Scale values: 1 (very low) to 5 (very high).

prior to the experience, mainly during lectures or classes. On the other hand, 64% of the students previously encountered an AMR application in real implementations or in web videos.

Focusing on the experience, 95% of the sample found it stimulating and exciting, and 90% declared that it increased their familiarity with automated warehouses. Moreover, almost the totality of the sample indicated that the experience encouraged them to consider or reinforced the idea of working in logistics. Additionally, most of the students considered the performed tasks quite easy, and they were perceived as difficult only by a few. Also, the degree of difficulty in using the WMS was considered either low or very low by 86% of the sample.

By focusing on students' perception of the impacts that automation could have on warehouse operations (Table 2), put- away and inbound time, storage and retrieval time, number of errors, and throughput were perceived to be warehouse KPIs strongly affected by industrial automation. Moreover, a relevant number of students stated that automation may have a moderate impact on the floor area required for implementing the associated systems. Many students also found that operators' fatigue is strongly influenced, while the skill set required to work with automated warehouses was not perceived to be as affected. On the contrary, the simplification of work for operators was recognized as an element heavily impacted. Additionally, 91% of the students thought that AMRs can effectively support AS/RSs, while 8% viewed their implementation with very low effects. Moreover, 53% of the students assessed that sometimes the work pace can be too relentless, while the level of stress was perceived to be moderately or highly impacted by 26% of the sample.

Since the data were based on a Likert scale, and the records were not normally distributed, a non-parametric approach needed to be adopted (Minardi et al., 2023). Kendall's $\tau$-$b$ was used to examine possible concordance between each pair of survey items among respondents, since the observations were ordinal, based on a Likert scale, and not normally distributed (Arndt et al., 1999; Allison et al., 2022). A very weak relationship can be associated with a coefficient lower than 0.1, weak with 0.3, medium with 0.5, strong with 0.7, and very strong with 0.9 (Khavidaki et al., 2022). The level of significance of the test was set to 5% (De Marco et al., 2021). The results from the test showed that the students evaluated some potential impacts of the AS/RS with a moderate degree of concordance (Table 3). For instance, they stated that knowledge enhancement is positively correlated with the enhancement of put-away and inbound time, which in turn is positively correlated with the potential improvement in the overall throughput of the warehouse. These results demonstrate that students were able to assess the operational benefits of AS/RS in accordance with the scientific literature to some extent (Zammori et al., 2021). On the one hand, the reduction of the operators' fatigue is correlated with easier work by the operator, while difficult operations are found to be correlated with an increased level of stress. Both correlations seem straightforward and demonstrate that students approached the survey rationally. Therefore, the results drawn from the questionnaire can be considered robust.

After checking the level of concordance of the responses to the questions, the Cronbach's $\alpha$ test was computed for every question of the survey proposed to the students to measure its internal consistency and thus to check the validity of the analysis performed. The coefficient ranges between 0 and 1, where higher values indicate higher consistency (Arditi et al., 2015). Values higher than 0.6 can be considered acceptable (Sarakatsianou et al., 2022). The results in Table 4 show that all the coefficients are higher than 0.6, meaning that the proposed questionnaire was correctly designed to capture the interests of the students about logistics topics and to understand their perception of the potential impacts that automated warehouses might have on performance.

Table 5 shows the outcomes of the KW test. For the two groups of students, mean, standard deviation, and median values are shown. Values of mean and standard deviation were computed to provide additional information related to dispersion and about the centrality of data, even if they are not normally distributed (Arcidiacono et al., 2023). It is worth noting that master's students claimed to be more interested in the experience and more generally in logistics. This might be due to a higher awareness and to a more solid cultural background. The higher level of education might have also affected other results. In fact, the perception of graduate students about the impacts of automated warehouses on the reduction of errors and the reduction of warehouse floor area was significantly higher compared with undergraduate students. Similarly, by considering human workload aspects, according to the Master's students, automation in warehousing processes might significantly enhance operational activities, while at the same time reducing the level of stress and fatigue of operators. As a consequence, Master's students considered automation in warehouse activities as a lever for increasing the operations performance and for ensuring a higher quality of life for operators, who can in turn be supported in carrying out their daily activities (Caputo et al., 2017).

DECISION SCIENCES JOURNAL OF INNOVATIVE EDUCATION



**TABLE 3** Rank correlation of survey items.

| | | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Interest in logistics | (1) | 0 | **0.41*** ** | −0.032 | 0.11 | 0.21* | 0.23* | −0.02 | **0.33** ** | 0.16 | 0.11 | 0.17 | 0.07 | 0.11 | **0.47*** ** | −0.07 | 0.14 |
| Satisfaction with the experience | (2) | | 0 | −0.21 | 0.11 | 0.15- | **0.38*** ** | −0.03 | 0.28** | −0.03 | 0.15 | 0.21* | 0.07 | 0.09 | 0.29** | 0.02 | −0.01 |
| Difficulty of the test | (3) | | | 0 | 0.07 | −0.11 | −0.06 | 0.09 | −0.06 | 0.06 | 0.16- | 0.05 | 0.02 | 0.08 | −0.08 | 0.09 | 0.1 |
| Usefulness of AMR | (4) | | | | 0 | 0.15 | 0.09 | 0.004 | −0.1 | 0.1 | 0.09 | 0.19* | 0.07 | 0.02 | 0.07 | −0.01 | 0.1 |
| Enhancement of knowledge | (5) | | | | | 0 | **0.31** ** | 0.11 | 0.27* | 0.03 | 0.12 | 0.14 | 0.11 | 0.01 | **0.31** ** | −0.04 | −0.26 |
| Enhancement of put-away and inbound time | (6) | | | | | | 0 | 0.14 | 0.25* | **0.31** ** | −0.11 | 0.16 | 0.18 | −0.09 | 0.02 | 0.09 | 0.09 |
| Enhancement of storage and retrieval time | (7) | | | | | | | 0 | 0.17- | 0.12 | −0.06 | 0.12 | 0.11 | 0.03 | 0.06 | −0.08 | −0.14 |
| Reduction of errors | (8) | | | | | | | | 0 | −0.02 | 0.1 | 0.19* | 0.11 | 0.11 | 0.11 | 0 | −0.01 |
| Throughput | (9) | | | | | | | | | 0 | −0.02 | 0.02 | −0.01 | −0.04 | 0.04 | 0.19* | 0.25* |
| Reduction of floor space | (10) | | | | | | | | | | 0 | 0.21* | 0.1 | 0.22* | 0.1 | 0.18 | 0.02 |
| Reduction of operators' fatigue | (11) | | | | | | | | | | | 0 | 0.21* | **0.45*** ** | 0.06 | 0.04 | −0.14 |
| Enhancement of operators' skill | (12) | | | | | | | | | | | | 0 | 0.22* | 0.09 | 0.06 | −0.09 |
| Easier operations | (13) | | | | | | | | | | | | | 0 | 0.04 | −0.14 | −0.21 |
| Change of interest in automated warehouse | (14) | | | | | | | | | | | | | | 0 | −0.05 | −0.03 |
| Operations difficulties | (15) | | | | | | | | | | | | | | | 0 | **0.31** ** |
| Level of stress | (16) | | | | | | | | | | | | | | | | 0 |

*$p$-value ≤ 0.05.
**$p$-value ≤ 0.01.
***$p$-value ≤ 0.001.
The bold values corresponds to the items which level of concordance is above 0.3.

**TABLE 4** Cronbach's $\alpha$ coefficient.

| Questionnaire item | Cronbach's $\alpha$ |
|---|---|
| Interest in logistics | 0.654 |
| Satisfaction with the experience | 0.676 |
| Difficulty of the test | 0.676 |
| Difficulty in using the warehouse software | 0.676 |
| Usefulness of AMR | 0.685 |
| Enhancement of knowledge | 0.675 |
| Enhancement of put-away and inbound time | 0.666 |
| Enhancement of storage and retrieval time | 0.675 |
| Reduction of errors | 0.664 |
| Throughput | 0.673 |
| Reduction of floor space | 0.660 |
| Reduction of operators' fatigue | 0.650 |
| Enhancement of operators' skills | 0.668 |
| Easier operations | 0.665 |
| Change of interest in automated warehouse | 0.677 |
| Operations difficulties | 0.691 |
| Level of stress | 0.707 |

## 4.2 | Medium-term impact

To study the medium-term effects of the hands-on experience, two OLR models with the same structure were built: one for Bachelor's students (Model A) and one for Master's students (Model B). The choice of having two separate models was due to the fact that both the size of the two samples and the two academic programs were different (286 Bachelor's and 28 Master's students). The ordinal response variable was the factor Evaluation, representing the result obtained at the exam. It was considered at 4 levels: Insufficient, Low, Medium, High. According to the Italian academic evaluation system (based on the Italian scale between 1 and 30 *cum laude*, in which the sufficiency corresponds to 18), the grade was categorized as insufficient if lower than or equal to 17, low if between 18 and 22, medium if between 23 and 26, high if greater than or equal to 27. The main predictor was represented as a dichotomous variable depicting the participation in the hands-on experience (i.e., "Yes" if the student participated in the hands-on experience and "No" if the student did not participate in the experience). Two additional predictors were included in the models as control variables, namely, the Sex (dichotomous variable assuming the levels Male and Female) and the Attempts (discrete variable indicating the number of attempts before successfully passing the exam). Table 6 presents the distribution of the response variable (i.e., exam evaluation across Bachelor's and Master's students). The data were further divided between students who participated in the hands-on experience and those who did not. Most undergraduate students received low marks, regardless of their participation in the hands-on experience. By contrast, graduate students performed better, achieving medium to high grades, with the hands-on experience seeming to have a positive impact on their exam results.

The results of the 2 OLR models are proposed in Table 7. Each model presents a set of statistics. Specifically, in OLR a coefficient is estimated for each variable in the model, along with a constant term for all but one of the outcome categories. These constant terms, along with the variable coefficients, create a series of binary regression equations. The first equation predicts the likelihood of the first event. The second predicts the likelihood of the first or second event. The third predicts the likelihood of the first, second, or third event, and so forth. The standard error of each coefficient reflects the variability to be expected from repeatedly sampling the same population. The *Z*-value, a test statistic, represents the ratio of the coefficient to its standard error, and the *p*-value assesses the strength of evidence against the null hypothesis. The odds ratio, a key metric, compares the odds of two events occurring. The odds of an event are calculated by dividing the probability of the event occurring by the probability of it not occurring. Confidence intervals provide a range of values within which the true odds ratios are likely to fall (Montgomery, 2017).

Looking at Model A, there was no statistical significance in participating at the hands-on experience. On the other hand, it is possible to observe a statistical significance in the number of attempts prior to passing the exam.

Focusing instead on Model B, a significance in participating at the experience was detected. The negative coefficient and the odds ratio lower than 1 associated with the predictor indicate that the experience had positive effects on the mark obtained at the final exam. This aspect is also supported by the number of attempts in Model B, that was not statistically significant, and by the result of Table 6.

By comparing the results of the OLR models built, it can be stated that the experience presented might be more effective if proposed to Master's students rather than to Bachelor's students. This can be due to a higher awareness of Master's students regarding logistics and warehousing processes. Such a result is coherent to the outcomes of the KW test, in which graduate students stated to be more interested in logistics topics and showed greater interest about the experience. The more established and deeper knowledge of Master's students, consolidated during the previous academic years, could facilitate the learning process through a hands-on experience similar to the one described in this study. Additionally, graduate students have attended courses focused on the design of equipment part of manufacturing processes, so they are probably more keen to figure out and evaluate the impacts of the physical equipment involved in the experience on logistics activities and their related performance. Finally, it should not be neglected that a considerable number of Master's students already had some confidence with industrial and warehouse contexts, thanks to their experience acquired during company internships for developing their Bachelor's final project. These findings demonstrate that it is better to propose the

DECISION SCIENCES JOURNAL OF INNOVATIVE EDUCATION




**TABLE 5** Kruskal–Wallis test results.

| | Bachelor's degree | | | Master's degree | | | |
|---|---|---|---|---|---|---|---|
| **Questionnaire item** | **Mean** | **St.Dev.** | **Median** | **Mean** | **St.Dev.** | **Median** | ***p*-value** |
| Interest in Logistics | 4.37 | 0.71 | 4 | 4.6 | 0.50 | 5 | 0.040* |
| Satisfaction with the experience | 4.48 | 0.56 | 4 | 4.5 | 0.51 | 5 | 0.032* |
| Difficulty of the test | 1.96 | 0.77 | 2 | 2.25 | 0.97 | 2 | 0.329 |
| Difficulty in using the warehouse software | 1.96 | 0.77 | 2 | 2.25 | 0.96 | 2 | 0.328 |
| Usefulness of AMR | 3.52 | 0.89 | 4 | 3.55 | 0.94 | 4 | 0.207 |
| Enhancement of knowledge | 4.22 | 0.58 | 4 | 4.2 | 0.62 | 4 | 0.85 |
| Enhancement of put-away and inbound time | 4 | 0.67 | 4 | 4.1 | 0.72 | 4 | 0.738 |
| Enhancement of storage and retrieval time | 4.37 | 0.82 | 4 | 4.15 | 0.93 | 4 | 0.87 |
| Reduction of errors | 4.29 | 1.01 | 4 | 4.55 | 0.51 | 5 | 0.043* |
| Throughput | 4.26 | 0.79 | 4 | 4.4 | 0.99 | 5 | 0.487 |
| Reduction of floor space | 3.96 | 0.92 | 4 | 4.2 | 0.89 | 5 | 0.012* |
| Reduction of operators' fatigue | 4.44 | 0.98 | 4.5 | 4.55 | 0.69 | 5 | 0.026* |
| Enhancement of operators skills | 3.52 | 1.15 | 4 | 3.15 | 1.23 | 4 | 0.777 |
| Easier operations | 4.26 | 0.74 | 4 | 4.45 | 0.76 | 5 | 0.004** |
| Change of interest in automated warehouse | 3.96 | 0.78 | 4 | 3.9 | 0.65 | 4 | 0.285 |
| Operations difficulties | 1.67 | 0.64 | 2 | 1.75 | 0.64 | 2 | 0.734 |
| Level of stress | 2.18 | 0.56 | 2 | 2.4 | 0.60 | 3 | 0.012* |

*$p$-value $\leq 0.05$.
**$p$-value $\leq 0.01$.
***$p$-value $\leq 0.001$.

**TABLE 6** Frequency in the response variable.

| | | Bachelor's students | | Master's students | |
|---|---|---|---|---|---|
| **Level** | **Value** | **No hands-on experience** | **Hands-on experience** | **No hands-on experience** | **Hands-on experience** |
| 1 | Insufficient | 16 | 7 | 1 | 0 |
| 2 | Low | 163 | 24 | 1 | 0 |
| 3 | Medium | 46 | 13 | 9 | 7 |
| 4 | High | 13 | 4 | 2 | 8 |
| Total | | 238 | 48 | 13 | 15 |

present experience to Master's students that are more able to capture the main operational implications of exploiting automation in warehouse processes.

## 5 | CONCLUSIONS

This study proposes a newly designed hands-on experience in a LF environment that focuses on operational aspects of warehouse logistics. In particular, a group of 62 industrial engineering students were tasked with performing typical processes of a distribution center in a university LF. Additionally, the level of awareness and interest toward automated warehouses was evaluated through a questionnaire administered at the end of the experience. Results demonstrated that innovative teaching approaches that replicate real business scenarios might be effective in facilitating students' scientific and professional knowledge, while at the same time increasing their motivation and engagement. The hands-on experience discussed here can support the achievement of key LOs that characterize university logistics courses that focus on both physical and information flows in warehouses regarding automated systems (Wagner et al., 2020; Woschank & Pacher, 2020c). The results were also analyzed at an empirical level. The two findings appear to be highly correlated. In continuity with previous literature, the proposed hands-on experience was found to be more effective as a learning tool for Master's students (Stuart, 2014). Likewise, more experienced students expressed an increased positive outlook on the potential impacts of the AS/RS technology, such as improved performance and reduced errors and stress. These results suggest that experienced students are more optimistic

**TABLE 7** OLR models.

| Model | Predictor | Coefficient | SE coefficient | *Z*-value | *P*-value | Odds ratio | Lower | Upper |
|---|---|---|---|---|---|---|---|---|
| Model A | Const(1) | −4.23065 | 0.454934 | −9.30 | 0.000*** | | | |
| (Bachelor's students) | Const(2) | −0.400895 | 0.314560 | −1.27 | 0.202 | | | |
| | Const(3) | 1.38300 | 0.369923 | 3.74 | 0.000*** | | | |
| | Experience (level Yes) | −0.206926 | 0.328082 | −0.63 | 0.528 | 0.81 | 0.43 | 1.55 |
| | Sex (level M) | 0.227561 | 0.260981 | 0.87 | 0.383 | 1.26 | 0.75 | 2.09 |
| | Attempts | 0.934621 | 0.177360 | 5.27 | 0.000*** | 2.55 | 1.80 | 3.60 |
| Model B | Const(1) | −3.15715 | 1.96212 | −1.61 | 0.108 | | | |
| (Master's students) | Const(2) | −2.37282 | 1.82072 | −1.30 | 0.192 | | | |
| | Const(3) | 1.48852 | 1.75648 | 0.85 | 0.397 | | | |
| | Experience (level Yes) | −2.22315 | 1.01011 | −2.20 | 0.028* | 0.11 | 0.01 | 0.78 |
| | Sex (level M) | 0.842435 | 1.10833 | 0.76 | 0.447 | 2.32 | 0.26 | 20.38 |
| | Attempts | −0.125401 | 0.775092 | −0.16 | 0.871 | 0.88 | 0.19 | 4.03 |

*$p$-value ≤ 0.05.
**$p$-value ≤ 0.01.
***$p$-value ≤ 0.001.

when evaluating the benefits of technology and, consequently, more motivated in the learning process when using it first-hand.

## 5.1 | Implications for practitioners and academicians

Thus, the knowledge of industrial and logistics technologies provided by innovative teaching methods could further boost the awareness of today's students and facilitate their integration in modern working scenarios, especially if this opportunity is given in the second part of university programs. In fact, at that point of the learning process, such teaching approaches can better support the medium-term knowledge about the characteristics and the potentialities of warehouse automation that helps decision-making in the students' future professional life. By folding the hands-on experience into the learning process of undergraduate students, we aimed to create a scalable and adaptable model. However, the successful replication of this approach is inherently dependent on the specific context, as the hands-on experience is closely tied to the availability of a LF environment. While the methodology and pedagogical principles can be applied broadly, full implementation requires that institutions have the necessary infrastructure and resources to develop a similar immersive learning space, by applying to national or international funding schemes.

The warehouse LF presented in this work can also offer a dynamic and interactive way to teach operations management in business schools, particularly in supply chain management and logistics courses. In fact, by providing practical experience with advanced technologies, such as AS/RSs and AMRs, it can foster critical thinking, problem-solving, and decision-making abilities, which are essential for the development of successful careers in operations management. In particular, understanding how AS/RSs and AMRs function and interact provides valuable insights into automation and its impact on efficiency and productivity. Moreover, the use of AMRs for material handling within the LF allows students to observe and actively participate in the movement of goods in a controlled environment. This enables them to understand the complexities of material flow, inventory management, and logistics processes. Since business school curricula emphasize decision-making, the LF could be further leveraged for exercises involving critical choices on warehouse type, inventory replenishment policies, and material flow optimization strategies. Coupling these practical activities with a preceding case study discussion on warehouse management would provide students with a solid theoretical foundation, enriching their ability to apply learned concepts in real-world scenarios. Ultimately, through the warehouse LF facilities, students can experiment with different strategies to optimize the application of automated storage and material handling systems to improve operational efficiency. In such a way, the presented LF can support learning about warehouse layout, picking strategies, and route optimization.

Manufacturing and logistics companies interested in enhancing the skills of their managers on the advantages, disadvantages, and implications of implementing automated storage and material handling systems might use this work to develop partnerships with universities to engage their key human resources in similar LFs and hands-on experiences, according to a continuous learning process.

The present work also contributes to a promising research stream on structured and quantitative evaluation of teaching activities based on the practical involvement of students. Such an aspect becomes crucial in the logistics arena, wherein most of the existing teaching practical experiences are associated with qualitative assessments of their impacts on students (May, 2021), usually focusing on the short-term ones only, that is, those induced in the participants right after carrying out the experience (Schlüter & Kretschmer, 2020). Furthermore, the experience and evaluation scheme proposed in this article can support the design and application of new teaching approaches and hands-on experiences that help both students and professionals master Industry 4.0 and 5.0 concepts that focus on manufacturing and logistics settings. Finally, the presented LF, together with the associated hands-on experience, promotes the development of research about LFs in two ways. First, they contribute to the still under-explored field of logistics LFs (Bellucci et al., 2022). Second, they foster studies about not only how to design and implement LFs, but also on the quantitative assessment of the impacts of their activities on learners' knowledge advancement.

## 5.2 | Limitations

This research has several limitations. First, the results of the hands-on experience are based on a limited number of people involved at the Master's level, given the small number of students enrolled in the focused I4.0 PS course. Second, the results are related to only one academic year and two courses. Therefore, future research will consolidate the results achieved in the present research by replicating the experience with an increased number of Master's students. Additionally, a more complete application campaign including more courses from different engineering programs and extending over multiple academic years will be performed to more coherently evaluate the outcomes over a longer time span. This will allow for the comparison of the effects of the proposed experience on increasing the knowledge of students focused on different technical disciplines. Finally, in future sessions of the hands-on experience, students will be asked for suggestions for improvement, which will be used to refine the design of the experience and evaluated in future studies.

## ACKNOWLEDGMENT

Open access publishing facilitated by Politecnico di Torino, as part of the Wiley - CRUI-CARE agreement.

## ORCID

*Andrea Ferrari* https://orcid.org/0000-0002-1920-5677
*Anna Corinna Cagliano* https://orcid.org/0000-0002-6283-1518
*Giovanni Zenezini* https://orcid.org/0000-0002-0996-6739
*Antonio Carlin* https://orcid.org/0000-0003-3876-2185
*Giulio Mangano* https://orcid.org/0000-0002-2792-505X

## REFERENCES

Abdulwahed, M. & Nagy, Z.K. (2009) Applying kolb's experiential learning cycle for laboratory education. *Journal of Engineering Education*, 98(3), 283–294.

Abele, E., Metternich, J., Tisch, M., Chryssolouris, G., Sihn, W., ElMaraghy, H. et al. (2015) Learning factories for research, education, and training. *Procedia CiRp*, 32, 1–6.

Allison, J.S., Santana, L. & Visagie, I. (2022) A primer on simple measures of association taught at undergraduate level. *Teaching Statistics*, 44(3), 96–103.

Anderson, L.W. & Krathwohl, D.R. (2001) *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*: Addison Wesley Longman, Inc.

Angrisani, L., Arpaia, P., Bonavolontá, F., Moccaldi, N. & Moriello, R.S.L. (2020) A learning small enterprise networked with a FabLab: An academic course 4.0 in instrumentation and measurement. *Measurement*, 150, 107063.

Arcidiacono, F., Ancarani, A., Di Mauro, C. & Schupp, F. (2023) Linking competitive priorities, smart manufacturing advancement and organizational microfoundations. *International Journal of Operations & Production Management*, 43(9), 1387–1408.

Arditi, D., Mangano, G. & De Marco, A. (2015) Assessing the smartness of buildings. *Facilities*, 33(9/10), 553–572.

Arndt, S., Turvey, C. & Andreasen, N.C. (1999) Correlating and predicting psychiatric symptom ratings: Spearmans *r* versus Kendalls tau correlation. *Journal of Psychiatric Research*, 33(2), 97–104.

Arvis, J.F., Saslavsky, D., Ojala, L., Shepherd, B., Busch, C. & Raj, A. (2016) Trade logistics in the global economy: The logistics performance index and its indicators. Working Paper 43005. World Bank.

Atieh, A.M., Kaylani, H., Al-Abdallat, Y., Qaderi, A., Ghoul, L., Jaradat, L. et al. (2016) Performance improvement of inventory management system processes by an automated warehouse management system. *Procedia Cirp*, 41, 568–572.

Ayuby, M., Ahmed, J. & Sarder, M. (2020) Integrated hands-on experience on students learning of logistics seniors. In *Proceedings of the 2016 Industrial and Systems Engineering Research Conference* (pp. 1797–1802).

Bellucci, M., Chiurco, A., Cimino, A., Ferro, D., Longo, F. & Padovano, A. (2022) Learning factories: A review of state of the art and development of a morphological model for an industrial engineering education 4.0. In *Proceedings of the MELECON 2022–IEEE Mediterranean Electrotechnical Conference* (pp. 260–265). IEEE.

Benaragama, Y. & Koomsap, P. (2020) Design and development of automated guided vehicles for active learning in material handling management for smart manufacturing operation. *International Symposium on Project Approaches in Engineering Education*, 10, 120–126.

Bergström, K., Billger, M., Fredriksson, A. & Janné, M. (2020) The mimic construction logistics game: Facilitating group discussion and understanding of construction logistics through gameplay. *IOP Conference Series: Earth and Environmental Science*, 588(5), 052014.

Caputo, A.C., Pelagagge, P.M. & Salini, P. (2017) Modelling human errors and quality issues in kitting processes for assembly lines feeding. *Computers & Industrial Engineering*, 111, 492–506.

Chadha, D. & Hellgardt, K. (2023) A case of conceptualisation: Using a grounded theory approach to further explore how professionals define engineering judgement for use in engineering education. *European Journal of Engineering Education*, 49, 348–369.

Culver, K., Bowman, N.A., Youngerman, E., Jang, N. & Just, C.L. (2022) Promoting equitable achievement in stem: Lab report writing and online peer review. *The Journal of experimental education*, 90(1), 23–45.

David, G., Woods, V., Li, G. & Buckle, P. (2008) The development of the quick exposure check (QEC) for assessing exposure to risk factors for work-related musculoskeletal disorders. *Applied ergonomics*, 39(1), 57–69.

De Marco, A., Mangano, G. & De Magistris, P. (2021) Evaluation of project management practices in the automotive original equipment manufacturers. *Procedia Computer Science*, 181, 310–324.

De Vin, L.J. & Jacobsson, L. (2017) Karlstad lean factory: An instructional factory for game-based lean manufacturing training. *Production & Manufacturing Research*, 5(1), 268–283.

Ekren, B.Y. (2020) A simulation-based experimental design for SBS/RS warehouse design by considering energy related performance metrics. *Simulation Modelling Practice and Theory*, 98, 101991.

Faller, C. & Feldmúller, D. (2015) Industry 4.0 learning factory for regional SMES. *Procedia CIRP*, 32, 88–91.

Ferrari, A., Carlin, A., Rafele, C. & Zenezini, G. (2024a) A method for developing and validating simulation models for automated storage and retrieval system digital twins. *The International Journal of Advanced Manufacturing Technology*, 131(11), 5369–5382.

Ferrari, A. & Mangano, G. (2023) Review of relevant literature on modelling and simulation approaches for AS/RSS. *IFAC-PapersOnLine*, 56(2), 3680–3685.

Ferrari, A., Mangano, G., Cagliano, A.C. & De Marco, A. (2022a) 4.0 technologies in city logistics: An empirical investigation of contextual factors. *Operations Management Research*, 16, 345–362.

Ferrari, A., Mangano, G., Zenezini, G. & Carlin, A. (2022b) A real simulation of automated warehouses processes: An academic experience with engineering students. In *Proceedings of the XXVII Summer School Francesco Turco*.

Ferrari, A., Verso, A., Carlin, A. & Rafele, C. (2024b) Simulation study of a multi-level shuttle system with in-rack picking stations. *IFAC-PapersOnLine*, 58(19), 848–853.

Ferrari, A., Zenezini, G., Rafele, C. & Carlin, A. (2022c) A roadmap towards an automated warehouse digital twin: Current implementations and future developments. *IFAC-PapersOnLine*, 55(10), 1899–1905.

Gento, A.M., Pimentel, C. & Pascual, J.A. (2021) Lean school: An example of industry-university collaboration. *Production planning & control*, 32(6), 473–488.

Guimarães, L.M. & Lima, R.d.S. (2021) Active learning application in engineering education: Effect on student performance using repeated measures experimental design. *European Journal of Engineering Education*, 46(5), 813–833.

Hamzeh, F., Theokaris, C., Rouhana, C. & Abbas, Y. (2017) Application of hands-on simulation games to improve classroom experience. *European Journal of Engineering Education*, 42(5), 471–481.

Harrell, F.E. (2015) Ordinal logistic regression. In: *Regression modeling strategies* (pp. 311–325). Springer.

Hoshimov, A., Cagliano, A.C., Mangano, G., Schenone, M. & Grimaldi, S. (2024) As/r system travel time in class-based storage with different input-output point levels: A proposed formula. *Journal of Facilities Management*, 22(1), 108–123.

Joshi, A., Kale, S., Chandel, S. & Pal, D.K. (2015) Likert scale: Explored and explained. *British journal of applied science & technology*, 7(4), 396.

Khavidaki, S., Rezaei Sharifabadi, S. & Ghaebi, A. (2022) Services personalization in digital academic libraries: A Delphi study. *Digital Library Perspectives*, 39(1), 39–61.

Kinzli, K.D., Kunberger, T., ONeill, R. & Badir, A. (2018) A low-cost approach for rapidly creating demonstration models for hands-on learning. *European Journal of Engineering Education*, 43(1), 79–89.

Klock, A.C.T., Wallius, E. & Hamari, J. (2021) Gamification in freight transportation: Extant corpus and future agenda. *International Journal of Physical Distribution & Logistics Management*, 51(7), 685–710.

Kolesnyk, O. & Bubeník, I.P., & capek, J. (2021) Cloud platform for learning factories. *Transportation Research Procedia*, 55, 561–567.

Kreitlein, S., Höft, A., Schwender, S. & Franke, J. (2015) Green factories Bavaria: A network of distributed learning factories for energy efficient production. *Procedia CIRP*, 32, 58–63.

Lang, S., Reggelin, T., Jobran, M. & Hofmann, W. (2018) Towards a modular, decentralized and digital industry 4.0 learning factory. In *Proceedings—2018 6th International Conference on Enterprise Systems* (pp. 123–128). IEEE.

Larsen, M.S.S., Lassen, A.H. & Nielsen, K. (2019) Process Innovation in Learning Factories: Towards a Reference Model. In: Ameri, F., Stecke, K.E., Von Cieminski, G., & Kiritsis, D. (Eds.) *Advances in production management systems. Production management for the factory of the future* (vol. 566, pp. 658–665). Springer International Publishing.

Lerher, T., Ficko, M. & Palcˇicˇ, I. (2021) Throughput performance analysis of automated vehicle storage and retrieval systems with multiple-tier shuttle vehicles. *Applied Mathematical Modelling*, 91, 1004–1022.

Li, F.F., Du, Y. & Jia, K.J. (2022) Path planning and smoothing of mobile robot based on improved artificial fish swarm algorithm. *Scientific Reports*, 12(1), 1–16.

Lin, C.C. & Chang, C.H. (2018) Evaluating skill requirement for logistics operation practitioners: Based on the perceptions of logistics service providers and academics in Taiwan. *The Asian Journal of Shipping and Logistics*, 34(4), 328–336.

Lutz, H. & Birou, L. (2013) Logistics education: A look at the current state of the art and science. *Supply Chain Management: An International Journal*, 18(4), 455–467.

Machet, T., Lowe, D. & Gütl, C. (2012) On the potential for using immersive virtual environments to support laboratory experiment contextualisation. *European Journal of Engineering Education*, 37(6), 527–540.

Marolt, J., Kosanic´, N. & Lerher, T. (2022) Relocation and storage assignment strategy evaluation in a multiple-deep tier captive automated vehicle storage and retrieval system with undetermined retrieval sequence. *The International Journal of Advanced Manufacturing Technology*, 118(9), 3403–3420.

May, M.D. (2021) Apply VR and simulation-based learning for logistics and warehouse design education. In *IEEE Global Engineering Education Conference (EDUCON)* (pp. 983–988). IEEE.

Menekse, M. (2020) The reflection-informed learning and instruction to improve students academic success in undergraduate classrooms. *The Journal of Experimental Education*, 88(2), 183–199.

Milisavljevic-Syed, J., Afy-Shararah, M., Sahin, O. & Salonitis, K. (2023) The learning factory through the sustainability lens. In *13th Conference on Learning Factories, CLF*. SSRN.

Minardi, F., Botta-Genoulaz, V. & Mangano, G. (2023) Sustainable supply chain management practices in food industry: Professionals perspective. *Supply Chain Forum: An International Journal*, *25*, 535–549.

Montgomery, D.C. (2017) *Design and analysis of experiments*. John Wiley & Sons.

Muschard, B. & Seliger, G. (2015) Realization of a learning environment to promote sustainable value creation in areas with insufficient infrastructure. *Procedia CIRP*, 32, 70–75.

Naim, M., Lalwani, C., Fortuin, L., Schmidt, T., Taylor, J. & Aronsson, H. (2000) A model for logistics systems engineering management education in Europe. *European Journal of Engineering Education*, 25(1), 65–82.

Nikandish, N., Kim, D. & Salvador, R.O. (2023) The effectiveness of a field observation exercise to learn process management. *Decision Sciences Journal of Innovative Education*, 21(2), 95–106.

Nikolic, S., Ros, M., Jovanovic, K. & Stanisavljevic, Z. (2021) Remote, simulation or traditional engineering teaching laboratory: A systematic literature review of assessment implementations to measure student achievement or learning. *European Journal of Engineering Education*, 46(6), 1141–1162.

Oke, A., Marfo, J.S., Kull, T., Rogers, D., Asare Marfo, A.F., Noor, M.H. et al. (2024) Investigating the effectiveness of gamification on supply chain operations knowledge and practice. *Decision Sciences Journal of Innovative Education*, 22(1), 50–67.

Öztürkogˇlu, Ö. (2020) A bi-objective mathematical model for product allocation in block stacking warehouses. *International Transactions in Operational Research*, 27(4), 2184–2210.

Pittich, D., Tenberg, R. & Lensing, K. (2020) Learning factories for complex competence acquisition. *European Journal of Engineering Education*, 45(2), 196–213.

Quinn, W., Cionca, V., Witheephanich, K. & Ozturk, C. (2022) A learning factory framework: Challenges and solutions for an Irish university. *IFAC-PapersOnLine*, 55(10), 631–636.

Rasovska, I., Deniaud, I., Marmier, F. & Michalak, J.L. (2022) Learning factory flextory: Interactive loops between real and virtual factory through digital twin. *IFAC-PapersOnLine*, 55(10), 1938–1943.

Redondo, A., Awodele, I.A. & Gento, A.M. (2022) Costs and learning factories. In: *International Conference on Quality Innovation and Sustainability* (pp. 1–9). Springer.

Rosano, M., Cagliano, A.C. & Mangano, G. (2022) Investigating the environmental awareness of logistics service providers: The case of Italy. *Cleaner Logistics and Supply Chain*, *5*, 100083.

Salinas-Navarro, D.E., Mejia-Argueta, C., Da Silva-Ovando, A.C. & Garay-Rondero, C.L. (2020) Going beyond traditional approaches on industrial engineering education. In *IEEE Frontiers in Education Conference (FIE)* (pp. 1–8). IEEE.

Samuel, S. & Anita, T. (2023) The relationship between trends in technology use and repurchase intention. *International Journal of Data and Network Science*, 7(1), 449–456.

Santos, L.C., Gohr, C.F. & Junior, M.V. (2012) Simulation of assembly operations using interchangeable parts for OM education: A handson activity with water pipe fittings. *International Journal of Operations & Production Management*, 32 (12), 1427–1440.

Sarakatsianou, C., Baloyiannis, I., Perivoliotis, K., Kolonia, K., Georgopoulou, S. & Tzovaras, G. (2022) Validation and scoring of the Greek version of the strategic and clinical quality indicators in postoperative pain management (SCQIPP) questionnaire. *Journal of PeriAnesthesia Nursing*, 37(6), 918–924.

Schenone, M., Mangano, G., Grimaldi, S. & Cagliano, A.C. (2020) An approach for computing as/r systems travel times in a class-based storage configuration. *Production & Manufacturing Research*, 8(1), 273–290.

Schlüter, C. & Kretschmer, V. (2020) Next level training in logistics: Evaluation of a virtual reality-based serious game for warehouse logistics. In *19th International Conference on Modeling and Applied Simulation* (pp. 138–145). CAL-TEK Srl.

Schmuck, R. (2021) Education and training of manufacturing and supply chain processes using business simulation games. *Procedia Manufacturing*, 55, 555–562.

Scott, R., Schmidt, E. & Newton, K. (2007) Implementing hands-on laboratory exercises in undergraduate education. In *2007 Annual Conference & Exposition* (pp. 12–844). American Society for Engineering Education.

Shah, B. (2021) What should be lean buffer threshold for the forward-reserve warehouse? *International Journal of Productivity and Performance Management*, 72(2), 361–387.

Iyer S., S, D., N, K., A, K. & Dharmawardhana, M. (2023) Conversion of a manufacturing lab as a learning factory to educate factories of the future concept. *Lecture Notes in Mechanical Engineering*, 827–835.

Srinivas, S. & Yu, S. (2022) Collaborative order picking with multiple pickers and robots: Integrated approach for order batching, sequencing and picker-robot routing. *International Journal of Production Economics*, 254, 108634.

Stuart, A. (2014) A blended learning approach to safety training: Student experiences of safe work practices and safety culture. *Safety Science*, 62, 409–417.

Vailati, S., Zanchi, M., Cimini, C. & Lagorio, A. (2023) A classification framework for analysing industry 4.0 learning factories. In: *IFIP International Conference on Advances in Production Management Systems* (pp. 392–402). Springer.

Vodenicharova, M. et al. (2022) Gamed-based learning in higher education. *TEM Journal*, 11(2), 779–790.

Wagner, C., Sancho-Esper, F. & Rodriguez-Sanchez, C. (2020) Skill and knowledge requirements of entry-level logistics and supply chain management professionals: A comparative study of Ireland and Spain. *Journal of Education for Business*, 95(1), 23–36.

Weidig, C., Menck, N., Winkes, P.A. & Aurich, J.C. (2014) Virtual learning factory on VR-supported factory planning. *IFIP Advances in Information and Communication Technology*, 434, 455–462.

Wilson, S. (2018) Understanding bottlenecks: An operations management experiential learning exercise. *Decision Sciences Journal of Innovative Education*, 16(3), 166–184.

Woschank, M. & Pacher, C. (2020a) A holistic didactical approach for industrial logistics engineering education in the LOGILAB at the Montanuniversitaet Leoben. *Procedia Manufacturing*, 51, 1814–1818.

Woschank, M. & Pacher, C. (2020b) Program planning in the context of industrial logistics engineering education. *Procedia Manufacturing*, 51, 1819–1824.

Woschank, M. & Pacher, C. (2020c) Teaching and learning methods in the context of industrial logistics engineering education. *Procedia Manufacturing*, 51, 1709–1716.

Wu, Y., Chen, Y. & Wang, J. (2004) Skill requirements for logistics licenses. In: *2004 IEEE International Engineering Management Conference* (vol. 3, pp. 1198–1202). IEEE.

Zammori, F., Neroni, M. & Mezzogori, D. (2021) Cycle time calculation of shuttle-lift-crane automated storage and retrieval system. *IISE Transactions*, 54(1), 40–59.

Zarte, M., Wermann, J., Heeren, P. & Pechmann, A. (2019) Concept, challenges, and learning benefits developing an industry 4.0 learning factory with student projects. In *IEEE International Conference on Industrial Informatics (INDIN)* (pp. 1133–1138). IEEE.

Zenezini, G., Mangano, G. & De Marco, A. (2022) Experts' opinions about lasting innovative technologies in city logistics. *Research in Transportation Business & Management*, *45*, 100865.

**How to cite this article:** Ferrari, A., Cagliano, A.C., Zenezini, G., Carlin, A. & Mangano, G. (2025) Learning factory in logistics: Evaluation of the effects of a hands-on experience for automated warehouse processes. *Decision Sciences Journal of Innovative Education*, e70015. https://doi.org/10.1111/dsji.70015

## AUTHOR BIOGRAPHIES

**Andrea Ferrari** is Post-Doctoral Researcher at the Department of Management and Production Engineering at Politecnico di Torino. In spring 2025, he earned his PhD in Management, Production and Design at the Politecnico di Torino. From August 2023 to March 2024, he was a visiting researcher at Boston University, Metropolitan College. His research activities are focused on the application of digital twin, simulation approaches, statistical models and machine learning to the field of industrial logistics systems and supply chains. He is also lecturer of Industrial Plants and Supply Chain Management.

**Anna Corinna Cagliano** is Full Professor at the Department of Management and Production Engineering at Politecnico di Torino. She teaches Industrial Plants, Logistics, and Supply Chain Management. She was Visiting PhD student at Massachusetts Institute of Technology (MIT), Cambridge, MA. Her research is in the field of logistics and supply chain in both manufacturing and healthcare industries, with a particular focus on supply chain design through digital technologies, optimization of warehouse processes, and applications of Lean Manufacturing to supply chain management.

**Giovanni Zenezini** is Assistant Professor in the Department of Management and Production Engineering at the Politecnico di Torino since 2021. From 2018, he was Post-Doctoral Researcher with the Reslog group at the Politecnico di Torino, where he also earned his PhD in Production Management and Design in 2018. His research focuses on impact assessment of last-mile logistics initiatives, modeling of complex industrial systems with a particular emphasis on intra-logistics and project management. He is Reviewer for high-impact factor journals including *International Journal of Logistics Research and Applications*, *Journal of Simulation*, *Transportation Research Part A*, and *International Journal of Sustainable Transportation*.

**Antonio Carlin** obtained the Master's Degree (5-year degree) in Mechanical Engineering and is Confirmed Researcher and Aggregate Professor at the Department of Management and Production Engineering in Turin and a member of the RESLOG (Research Group for Engineering Systems and Logistics) research group. He deals with issues of industrial logistics, supply chain, handling systems and equipment, material handling, all topics on which he has had significant industrial relations over the years and numerous projects in the field. He has been member of the advisory board of AILOG (Italian Association of Logistics and Supply Chain Management).

**Giulio Mangano** earned his MSc in Management Engineering and his PhD in Production Systems and Industrial Design at Politecnico di Torino. Currently he is Associate Professor at the Department of Management and Production Engineering at the Politecnico di Torino. He is lecturer in Industrial Plants and Supply Chain, and Project Management courses. He was Visiting PhD Student at The Illinois Institute of Technology in Chicago. His research interests are in the fields of urban logistics, development of innovative supply chains, analysis of internal logistics processes with the application of digital technologies.