

# The LogiLegoLab: A Problem-based Learning Approach for Higher Education Institutions

**Jakob Kompatscher**

Chair of Industrial Logistics  
Montanuniversitaet Leoben  
Franz Josef-Strasse 18, 8700 Leoben, Austria  
jakob.kompatscher@stud.unileoben.ac.at

**Corina Pacher**

Resources Innovation Center  
Montanuniversitaet Leoben  
Franz Josef-Strasse 18, 8700 Leoben, Austria  
corina.pacher@unileoben.ac.at

**Manuel Woschank**

Chair of Industrial Logistics  
Montanuniversitaet Leoben  
Franz Josef-Strasse 18, 8700 Leoben, Austria  
manuel.woschank@unileoben.ac.at

## Abstract

Industry 4.0 concepts and technologies offer a multitude of possibilities for the systematic improvement of material and information flow processes in logistics systems. However, the usage of laboratories for the experimental testing and subsequent further development of Industry 4.0 approaches in industrial logistics still can be considered as an underdeveloped subject area in higher education institutions. Based on a problem-based learning approach, this paper investigates the recent literature on teaching and learning laboratories in the context of Industry 4.0 to identify the potential areas of action for an industrial logistics laboratory in the fields of research, academic teaching, and industry-related applications. Moreover, the authors develop a new concept for a module-based laboratory and derive implications for further research and industrial projects.

## Keywords

Industry 4.0; Smart Logistics; Logistics 4.0; Laboratory; Labs; Higher Education; Teaching and Learning Methods; Problem-based Learning

## 1 Introduction

The usage of new concepts and technologies of Industry 4.0 is becoming increasingly relevant for manufacturing companies. Thereby, technological progress plays a significant role in almost every industry, as it can have a significant influence on the long-term success of a company (Woschank and Zsifkovits 2020; Matt et al. 2020; Zsifkovits and Woschank 2019).

In small and medium-sized enterprises (SMEs), however, it is usually not possible to operate a separate research department that can systematically test new concepts and technologies before they are implemented in the company. A comprehensive solution to this issue may be the usage of Industry 4.0 laboratories which offer the experimental testing of new technologies and concepts as a service. This allows Industry 4.0 laboratories to evaluate potential problems and possible barriers in advance and thus test them without any entrepreneurial risk. Marian et al. state that laboratories play a very important role in the development of such concepts for the implementation of Industry 4.0. This can also be explained by the fact that most SMEs (small and medium-sized enterprises) lack the necessary resources for independent implementation. Thereby, the resources include financial resources as well as expertise in this complex area. This is exactly where laboratories get into the game, which mainly are operated by higher education institutions (Marian et al. 2019).

Existing Industry 4.0 laboratories are usually designed for a specific application. Therefore, such laboratories are usually only suitable for certain tests or only for predefined industries. There is currently no laboratory that is capable of modeling interdisciplinary processes from different industries in a flexible laboratory environment. For this reason, a special focus of new Industry 4.0 laboratories must be placed on the flexibility of the respective operational concept. Also, it is very important in Industry 4.0 research to find an interdisciplinary mix of different technologies, which, in combination, again lead to new disruptive changes. According to Pietro et al., more and more transdisciplinary collaborations are rising, and institutions are joining forces for a faster and better cooperative development (Prieto et al. 2019).

One example of this networked research is the Industry 4.0 platform of the German Federal Ministry of Economics and Energy. This platform is primarily concerned with the research and implementation of Industry 4.0 in German companies. However, they are also involved in international exchange and work on new topics in working groups of various experts (BMW 2020a). This platform represents a portal through which many laboratories exchange information. In Germany, there are 81 test centers, which work in the form of laboratories on new findings regarding further Industry 4.0 research to advance potential industrial applications (BMW 2020b).

To carry out profound research in a laboratory, various prerequisites are required. These include not only financial resources but also the expert knowledge of various specialists from different disciplines. These include well-trained specialists, who on the one hand are well versed in the topics of Industry 4.0 and, on the other, have expert knowledge concerning the professional methodological-didactical integration of pedagogical theories and methods regarding the use of laboratories. The industrial point of view can be generated through the permanent exchange with experts from the field of practice and must be permanently included in planning, implementation, and evaluation processes. Concerning the concepts and technologies of Industry 4.0, a broad expert knowledge is required, which includes overlaps, cross-connections, and divergences across the various topics of Industry 4.0. This is of great importance because new insights in this sector can rarely be achieved by using just a single technology. Moreover, in most cases, it is a mix of different technologies which, when combined, lead to new solutions. Such combined technologies usually make a greater contribution than approaches that try to completely create new technologies. Furthermore, a laboratory should not only conduct isolated research, thus it is better to establish profound findings based on research in cooperation with other laboratories (Aris et al. 2017). From an educational science perspective, the situation is similar regarding expert knowledge. Following the manifold theories, methods, and approaches, professional micro-didactic planning is required as a goal-oriented structuring of courses in higher education institutions. These curricula can reduce complexity and provide professional and methodological security and orientation.

According to Stanik (2016) the planning takes place on four levels:

- Level 1: Cognitive orientation level
- Level 2: Cognitive strategy level
- Level 3: Material practice level
- Level 4: Social process level

Levels 1 and 2 are mental decision-making processes such as setting goals. In general, so-called indicative goals should be defined for longer courses, and so-called detailed goals should be worked out in shorter courses. Also, the courses should be structured with learning outcomes, which enable the coordination of verifiability, selection, and preparation of learning content, including methods, time, media, and social forms in the sense of constructive alignment (Biggs 2011). All these references must be put into relation to each other. Level 3 includes the compilation of teaching and learning materials and written plans. Here, 'pedagogical content knowledge' is achieved to be able to link technical and pedagogical knowledge stocks. Level 4 can include, for example, the participation of colleagues or clients in the planning process. The planning is also embedded in social goals such as competence development or emancipation and organizational goals, prerequisites, and equipment. In addition, the following Figure 1 displays the six decision fields, which are influenced by four factors (Stanik 2016).

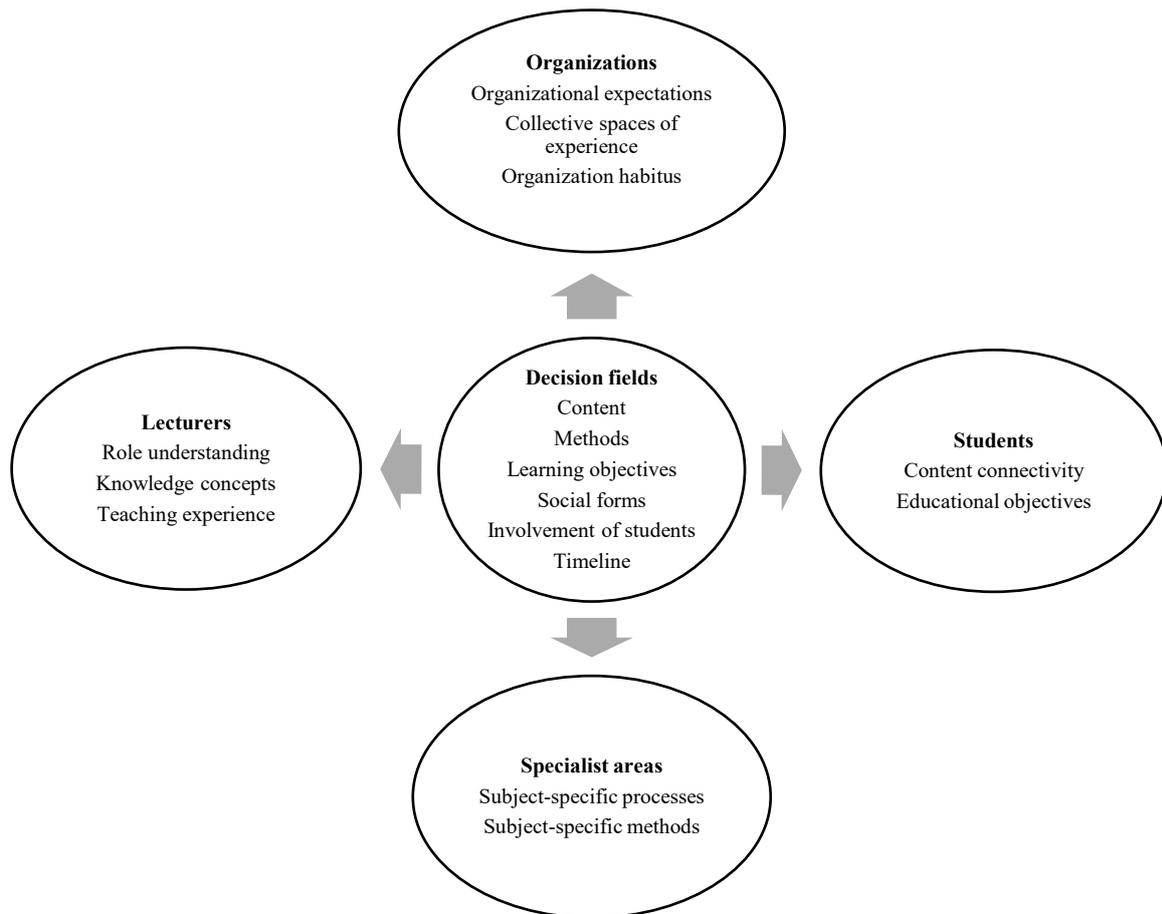


Figure 1. Decision fields and influencing factors based on Stanik (2016)

Based on the assessment of needs regarding research, academic teaching, and industry-related applications, this paper investigates requirements that are necessary for the three topics. Finally, these results will be amalgamated into a new laboratory concept. This concept describes how such a laboratory be established to cover the three topics regarding research, academic teaching, and industry-related applications in one laboratory.

## 2 Industry 4.0 – Overview of Technologies

Summarized, Industry 4.0 focuses on the networking of people, machines, and the products themselves. Since 1970, information technology has found its way into companies. Desktop PCs, the use of office IT, and the first computer-aided automation revolutionized the industry. With worldwide networks, new communication channels are being created which are becoming increasingly intelligent. This change is turning the entire industry upside down so that there is often titled ‘the new industrial revolution’ (Plattform Industrie 4.0 2020). These new developments, however, also bear the potential for great opportunities and developments to integrate technological advances into industrial processes, and, at the same time, increase competitiveness. The networking of products and machines increases efficiency, reduces costs, and saves resources. Intelligent networking makes it easier to keep an eye on everything and react more flexibly to changes, such as supplier failure or potential shortages of raw materials. In the following chapters, the authors will describe a set of selected technologies in more detail.

### 2.1 RFID System

RFID is the abbreviation for Radio Frequency Identification and is an identification technology that, in the past, was mainly used for animal identification, immobilizers, and access control.

Today, the importance of RFID systems is growing as they are now used for a multitude of emerging technologies. The main reason for this is that RFID manages to close the gap between the real and the virtual world. This means that, for example, it is possible to transmit information contactless through these transponders. For example, when a product with an RFID chip passes a reader, production information from the product is transmitted to the reader and then to the machine. Now the machine knows exactly what to do with the individual product. This means that production no longer must be managed by people who adjust the machine to the individual product, but the product itself says what needs to be done with it. The machine is then requested by the product itself to carry out a work step without any human intervention. A typical RFID system consists of a computer, a reader with a coupling unit,

and an RFID transponder. The computer is responsible for processing the data, but it also passes on commands. The reader with the coupling unit is responsible for passing on the data and, furthermore, supplies passive RFID transponders with the necessary energy. The energy transfer here is accomplished by electromagnetism. It should also be mentioned that there is still a wide variety of designs for the individual components. For example, there are even RFID transponders that are themselves equipped with a battery and sensors to transmit real-time data. It is important to notice that RFID transponders, in their simplest form, cost only 20-50 cents per unit. This makes it possible to use such chips almost everywhere to track any physical flow (Statista 2020; Fleisch and Mattern 2005).

## **2.2 Additive Manufacturing**

Also known as 3D printing, it is a technology that has also become increasingly important in recent years. This is evidenced by the fact that the 3D printing industry's revenue is expected to grow from \$3 billion in 2013 to over \$21 billion in 2021. This type of production is already widespread in the medical and dental sectors. Industrial production has not yet seen much of this technology. Reasons for this include the high acquisition costs of the machines and raw materials, limited choice of materials, and colors, sometimes inadequate surface quality, and difficulties in implementation (Hoffmann and Oettmeier 2016).

Experiments could be carried out in laboratories to successfully eliminate such problems and give many more industries access to this technology. Additive manufacturing needs to be well-researched and expanded because it hides a wide range of different possibilities. One of the most important advantages is the possibility to produce individual shapes and colors of various products. As a result, the variety of variants in production is becoming increasingly cost-effective. In addition, exact printing will save many jobs and the associated costs in the future since the complexity of production will be significantly reduced. For example, parts do not have to be milled, drilled, or formed by other machining processes because the printer prints the material in the desired form. This saves raw materials because the material is used more selectively and, therefore, less raw material is wasted (Hoffmann and Oettmeier 2016).

## **2.3 Collaborative Robots**

Conventional industrial robots can be used to perform heavy and dangerous work, which could be very risky for a person. They also usually work in isolated work areas where no human being has access when this heavy robot is doing its work. In contrast, there is the collaborative robot (Cobot) which is designed to work with and complement humans at the same workplace. These Cobots are usually lighter and more flexible than traditional industrial robots. They can usually perform several different tasks. They usually consist of an arm that can be equipped with various tools. It is also important to know that robots, in general, can have not only financial advantages but that a robot has other advantages, e.g., constant quality performance, in comparison to a human being. In the future, an ideal process will, therefore, be designed so that the power, endurance, and precision of robots, combined with the dexterity, flexibility, and creativity of humans will lead to highly efficient production (Sherwani et al. 2020).

## **2.4 Augmented Reality**

Augmented Reality (AR) is a technology that enables the projection of information from the virtual world into the real world. This is done by using glasses that project additional information onto the human eye. Thus, it is possible to make an extension in the human visual spectrum. Thereby, knowledge and information can be projected into the field of vision of a person without distracting from the real world. This technology is already successfully used for remote maintenance. The expert, who is not on-site, can watch the worker directly at work and project visual information into his field of vision. This way, the worker knows which screws he must tighten to perform maintenance (Fukuda et al. 2017). However, AR also has a variety of uses which will allow us to transfer and transmit information in a whole new dimension.

## **2.5 Big Data and Data Analytics**

The term 'Big Data' is defined as a huge and complex collection of data, with a range of Exabyte (= 1 million Terabyte) and more. These amounts of data exceed the possibilities of managing and efficiently processing such large data volumes. Science and industry agree that this flood of data creates new possibilities. The technical developments of our time make it easier to store and subsequently process more and more data. More research must be done in this area, as it has become clear that large amounts of data hide a lot of information from which new knowledge can be generated (Tiwari et al. 2018).

## **2.6 Machine Learning**

Machine Learning (ML) is a term that defines the science and technology of self-learning machines, with a special emphasis on learning computer programs. Machine learning is the automatic recognition of meaningful patterns in a wide variety of data sets. In a narrow sense, Deep Learning (DL) is defined as a subclass of ML. DL consists of several nonlinear layers of information processing for supervised or unsupervised feature extraction and transformation, and pattern analysis (Woschank et al. 2020a).

It is also worth mentioning that machine learning has existed for a very long time. The beginnings go back to 1943 when the first neural networks were mapped by machines. Now we are already so far advanced that ML has succeeded in giving people who are considered the best in their field worldwide cognitive superiority in tasks. Thus, we succeeded in creating an ML algorithm, which has managed to beat the mankind's best player in a highly complicated board game by using self-developed moves. This shows the potential of ML, because, in the future, there will be few tasks that a human can do better than a machine (MIT 2020).

## 2.7 Cloud and Edge Computing

Cloud and edge computing deal with the further processing of data that are created in a company. This involves processing the ever-increasing volumes of data. Therefore, the hardware and software used until now are no longer sufficient to process these large volumes of data. Therefore, new 'computing' technologies are used here.

A fundamental distinction can be made between cloud and edge computing for these services. As the name suggests, in cloud computing, data are stored, processed, and evaluated outside the company via the cloud. This information can then be accessed locally again. In contrast, in edge computing, the data are transferred directly via ethernet to various devices with computing power within the company and evaluated there. This is the more secure variant in terms of data protection, as the data do not have to be distributed over the Internet. A major disadvantage, however, is that edge computing has limited computing power. This depends on the company's computing power. So big data cannot be operated with edge computing alone. For the above-mentioned reason, it will, therefore, be important to find a mixture of cloud and edge computing. Confidential data could, thus, be evaluated locally via edge computing. The remaining less secure data would be processed in the cloud, where there are no limits to scalability (Bajic et al. 2019).

## 2.8 Digital Twins

A Digital Twin is a digital representation of a physical object, which makes it possible to test scenarios in the virtual world without exposing the physical object to risk. To map the state of the physical twin best digitally, sensor data are transmitted in real-time to ensure the permanent synchronization of the twins. Also, various scenarios can be simulated in parallel on the digital twin, which results can then be used as a basis for decisions on a wide range of options. As a result, there is much less interference and failures on the physical twin since major problems have already been detected and evaluated by the digital twin in advance. With the smart digital twin, artificial intelligence can make decisions based on the digital twin. This leads to the fact that the experience data, which originate from the digital twin, are processed and lead to optimal action strategies for the physical object (Tao et al. 2018).

In the context of Industry 4.0, it is becoming increasingly easy to create such digital twins, as more and more data are available, which makes it much easier to create a synchronous image in the digital world. Topics such as big data, cloud computing, and machine learning play an essential role in this process. When all these new technologies are used in combination, we will have a very powerful tool to eliminate errors and waste (Talkhestani et al. 2019).

## 3 Overview of Existing Industry 4.0 Labs

This chapter deals with the current laboratories, which already contribute to the further development of Industry 4.0. Thereby, laboratories 1-6 are identical with the Scopus query of Woschank and Pacher (2020). The laboratories 7-12 were determined by additional research in the course of this work. The identified laboratories are:

- The PuLL Learning Factory
- IFA's Learning Factory
- LEAD Factory
- Open Digital Lab for You
- AAU Smart Production Lab
- Automated Class Room
- Effiziente Fabrik 4.0
- Mirai-Lab
- MIT Megacity Logistics LAB
- Logistics 4.0 Lab
- Smart Mini Factory
- LogiLab

Table 1 shows that two laboratories did not use any of the previously identified Industry 4.0 technologies. The LEAD Factory is a factory where students assemble a scooter. They did not install any Industry 4.0 technologies.

The IFA Learning Factory is specialized in offering training courses on various topics such as factory planning, ergonomics at the workplace, lean production, and some more. However, in the opinion of the authors, little work is done in the direction of Industry 4.0.

Table 1. Identified Industry 4.0 laboratories

Labs	RFID-Systems	Additive-manufacturing	Collaborative Robot	Augmented Reality	Big Data and Data Analytics	Machine Learning	Cloud and Edge Computing	Digital Twin
1 PuLL	X		X					
2 IFA								
3 LEAD Factory								
4 DigiLab4U	X		X	X				
5 AUU	X		X		X	X		
6 Auto. Class R.	X	X	X					
7 Eff. Fab. 4.0	X				X			
8 Mirai-Lab			X	X				
9 Megacity					X			
10 Log. 4.0 Lab				X				
11 Smart Mini F.	X	X	X	X		X		
12 LogiLab		X		X				

It is also noticeable that none of the labs received a point in the cloud and edge computing or in the digital twin area. This has several reasons. On the one hand, it could be that too little emphasis was placed on IT-intensive topics in the research conducted by the laboratories. On the other hand, it must be considered that these topics are not very easy to work on a small scale.

In general, it can be said that existing laboratories usually only deal with a handful of selected technologies. This means that laboratories have been created which are only suitable for a small area of a branch. In the course of this paper, no laboratory was found that could provide a platform for testing Industry 4.0 technologies across industries and flexibly for different companies.

However, this interdisciplinary orientation would be very important. By achieving this, companies would also get the chance to test Industry 4.0 technologies before they are implemented. This problem does not play a central role for larger companies, because they usually can set up their test centers by themselves. These centers are then exclusively concerned with testing their company-specific scenarios, evaluating employees to schools, and related problems.

#### 4 Concept of the 'LogiLegoLab'

When designing the new laboratory, the aim is that it should contain all the technologies which were identified in this paper. To meet this requirement, it is especially important to find a method to allow the laboratory to grow slowly. This means that not everything has to be built at once. Also, this has the advantage that new modules can be continuously integrated later.

Furthermore, it is important to find a tool that works well across all modules, is not too expensive, and does not end up as waste.

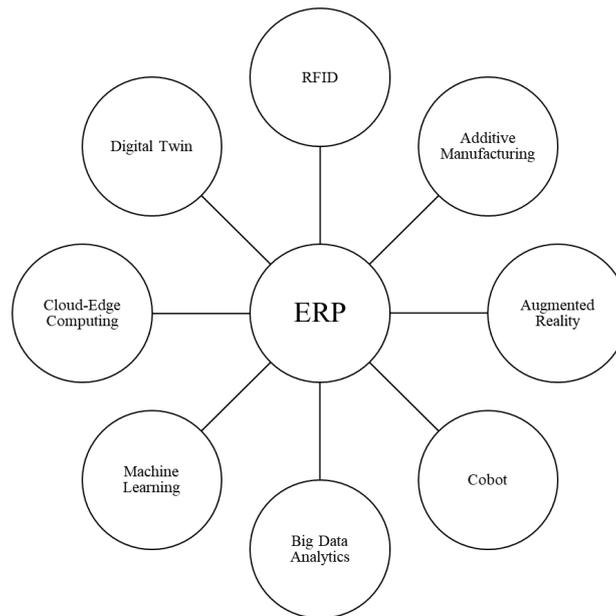


Figure 2. Technologies

Figure 2 shows an overview of all the ERP-related technologies that must be considered within a modern Industry 4.0 laboratory. The blue arrows are to show how the information flow is conceptualized. The ERP system is in the center and connects all technologies (Hofmann et al. 2018; Simons et al. 2017).

#### 4.1 Modularity

As already mentioned, a concept that allows slow growth and the integration of new modules is essential. Furthermore, each module should be designed in such a way that it works on its own, but through networking, becomes part of the whole system. This gives the possibility to redesign the laboratory in such a way that each experiment has its new subsystem, and that the laboratory is not bound to a fixed structure. This has the advantage of flexibility in terms of conversion, but also in terms of ongoing development by integrating new modules. When designing individual modules, care must be taken to create a uniform interface so that the module can be easily interlinked with others. Also, it should be designed in a way that it works on its own and is independent from other modules.

Therefore, the design of the new laboratory must be clarified in advance. Thus, before starting the reconstruction, a uniform solution should be found to meet all requirements of the potential modules, but still be compatible with each other. This compatibility should be given concerning IT, but also concerning the tools and the physical transfer of the tools (Dallasega et al. 2020; Woschank et al. 2020b; Dallasega et al. 2019; Wermann et al. 2019).

#### 4.2 Lego as the Central Tool

During the search for a suitable tool that meets the requirements, the idea of using Lego was born. The criteria which had to be fulfilled were defined as follows:

- Good value for money
- Can be used in different scales
- Can be produced by additive manufacturing
- Possibility for manual handling
- Can be assembled by humans or robots
- Later reusable
- Little space required for storage

As already described above, the decision for the ideal tool was made on Lego because it has many advantages over others. For example, Lego is easy to assemble, can be expanded by 3D printing, can be handled on a small or large scale, and is easily available and inexpensive.

When using Lego, it is also advantageous that various industrial goods can be represented by Lego. This, in turn, has the advantage that everyone can imagine something. As a result, there is at least a certain familiarity with the flux in training courses.

### 4.3 Application

In the following paragraphs, the authors describe the possible fields of application of the new laboratory. Thereby, we distinguish between the fields of research, academic teaching, and industry-related applications.

#### 4.3.1 Research

The LogiLegoLab should serve for research so that there is a possibility to work on new concepts regarding Industry 4.0. The laboratory should not only be accessible for industrial logisticians, but also for all other courses of studies at the university. Thereby, a broader spectrum of technical know-how is brought into the laboratory. The exchange of different fields of study also provides different perspectives on individual topics, which, in turn, leads to better research.

In terms of research, the modular design of the laboratory offers countless possibilities, as the design of the experimental environment is not limited in any way. Also, a wide variety of control concepts can be developed, since Lego provides a realistic framework for the investigation of material flows.

#### 4.3.2 Academic Teaching

The laboratory can be used in teaching in many ways. Here the pedagogical approach of problem-based learning can be applied. In this context, for Hmelo-Silver problem-based learning (PBL) is an instructional method in which students learn through facilitated problem-solving. In PBL, student learning centers on a complex problem that does not have a single correct answer. Students work in collaborative groups to identify what they need to learn to solve a problem (Hmelo-Silver 2004). The method of problem-based learning contributes on the one hand to the development of scientific knowledge and on the other to the development of essential competences. The students should be able to combine the already acquired knowledge with interdisciplinary competences such as communication skills, creativity, or problem-solving skills in real problems or challenges to develop the best possible solution to the problem. Ergo, through the PBL approach, the students can acquire the skills needed for lifelong learning. Due to this form of learning, the students should be put in the focus and the course leaders take a back seat. They take on an advisory function. Accordingly, the students themselves are challenged to actively deal with this problem, either alone or in a group, in two ways. On the one hand, the laboratory offers the possibility to convey various learning contents in a targeted manner and with practical relevance based on predefined scenarios. On the other hand, it also offers students the opportunity to gain insights by trial and error, in line with the motto 'learning by doing', i.e., the practical examination of real challenges. This teaching and learning method contributes significantly to the transfer of knowledge from theory to practice for students.

Due to the complexity of the laboratory, the following additional modules can be integrated into teaching:

- The treatment of a problem within the framework of a laboratory exercise
- Extend courses through experiments
- Offer project work
- Bachelor and Master theses for the design of new modules
- Build-in simulation games and offer them for learning purposes

The implications presented here should support the teaching by having a practice-oriented influence on the teaching. This can significantly improve the quality of teaching, which, in turn, can have a positive effect on the motivation of students. By assigning Bachelor and Master theses, for the conception of new modules, the growth of the laboratory can also be ensured. Furthermore, students can contribute their ideas and thereby acquire new skills.

#### 4.3.3 Industry-related Applications

In order not to neglect the practical relevance to business, a laboratory must also become a potential contact point for the industry. In this way, the practical relevance of the laboratory can be ensured. To demonstrate a certain attractiveness for industry, the laboratory should include the following activities:

- Possibility for employee training
- Offer virtual simulations
- Display simulations in the laboratory environment
- Showing potentials
- Offer concepts for the implementation of Industry 4.0
- Realizing projects together

These activities illustrate the importance of an open design so that it can be used for any kind of cooperation. This openness leads to the fact that an exchange of ideas can bring about other new findings. Also, it offers students the opportunity to acquire skills through projects with companies, which they will later need in the industry. After all, the laboratory should become a kind of platform for the exchange and development of new knowledge.

## 5 Conclusion

In front of a techno-economics background (Zunk 2018), the paper presents a concept for the 'LogiLegoLab'. Care was taken to ensure that all the previously discussed topics were considered in this laboratory. This has resulted in a laboratory that can be designed very flexibly. This concept also makes it possible to continuously integrate new modules with new technologies into the laboratory. Lego as a tool, which should represent the flow of goods in the laboratory, was also defined. Furthermore, possibilities were shown how aspects of research, academic teaching, and industry-related applications can be integrated into the laboratory in the future.

It would be important that, in the future, more institutions should focus on the concepts and technologies of Industry 4.0. This could, with the help of intelligent technologies, solve many problems. To make progress in this area, it will also be important to work together on new solutions within a laboratory-based network. Research should be as open and free as possible. Nobody should feel threatened by another laboratory, but rather the possible collaborations should be strengthened in the future. This would be a big step forward in terms of understanding the advantages of Industry 4.0.

Concerning this work, it would be desirable for the future if the implementation of a new laboratory would be successful. This requires motivated university personnel who, on the one hand, convince the curriculum commission to open towards new teaching and learning methods and integrate them into the current curricula. On the other hand, the industrial partners must also be convinced by profound research results to invest in this method. In addition to the financial aspect, the current problems and challenges of practice must also be methodologically and didactically professionally prepared to guarantee a suitable learning environment for the students (Woschank and Pacher 2020; Zunk and Sadei 2015).

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## Biographies

**Jakob Kompatscher** is currently a master student at the Montanuniversitaet Leoben. He specializes in Logistics Management and Automation. At the same university, he also completed his bachelor’s degree. In his bachelor thesis, he developed a new concept for the existing LogiLab. His research interests include the areas of Industry 4.0 concepts and technologies, transportation systems, sustainable management, and vertical farming.

**Corina Pacher** is an Education Project Manager at the Resources Innovation Center in Leoben. She studied pedagogical and educational science at the University of Klagenfurt with a specialization on social and inclusive education as well as on professional education. During and after her studies, she gained work experience, e.g., as the head of educational programs and in different social public service enterprises as social education worker. Currently, she is mainly focusing on raising the awareness for a resource-orientated handling of raw materials by connecting research, education, and society, e.g., by building and expanding skills and competencies of students through training initiatives.

**Manuel Woschank** received a diploma degree in industrial management and a master’s degree in international supply management from the University of Applied Sciences, FH JOANNEUM, Graz, Austria, and a Ph.D. degree in management sciences with summa cum laude from the University of Latvia, Riga, Latvia. He is currently a Senior Researcher, Senior Lecturer, and the Deputy Head of the Chair of Industrial Logistics at the Montanuniversitaet Leoben and an Adjunct Associate Professor at the Faculty of Business, Management and Economics at the University of Latvia. He was a visiting scholar at the Technical University of Kosice (Slovakia), and at the Chiang Mai University (Thailand). His research interests include the areas of logistics system engineering, production planning and control systems, logistics 4.0 concepts and technologies, behavioral decision making, and industrial logistics engineering education.

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