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► **To cite this version:**

Giovanni Lugaresi, Nicla Frigerioa, Andrea Matta. A New Learning Factory Experience Exploiting LEGO For Teaching Manufacturing Systems Integration. 10th Conference on Learning Factories, CLF2020, Apr 2020, Graz, Austria. 10.1016/j.promfg.2020.04.106 . hal-03880564

HAL Id: hal-03880564

<https://hal.science/hal-03880564>

Submitted on 1 Dec 2022

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10th Conference on Learning Factories, CLF2020

A New Learning Factory Experience Exploiting LEGO For Teaching Manufacturing Systems Integration

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Abstract

Involving and stimulating students through intensive work in computer laboratories and simulation projects might be a challenging task, often due to the lack of the real manufacturing system that must be modeled and improved. Indeed, studying a manufacturing system that cannot be observed represents a real obstacle for student effective learning. In this paper, we describe the “LEGO FACTORY” initiative, an extra-curricular experience within the Master Degree Study Programme in Mechanical Engineering of Politecnico di Milano. The initiative is open to students from any study course of the university. The goal is to exploit learning-by-playing principles to offer scholars the possibility to understand the most common issues in the design and management of manufacturing systems, with a focus on system integration. A miniaturized production system made by intelligent modules with LEGO® MINDSTORMS® is provided to students who are asked to accomplish a project aiming at the improvement of the system performances. The participants work in teams and must introduce design modifications and develop technical solutions to address the requirements. The experience is described with the hope that the approach can be replicated in other environments.

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Peer-review under responsibility of the scientific committee of the 10th Conference on Learning Factories 2020.

Keywords: LEGO, learning factory, system integration, learning-by-play.

1. INTRODUCTION

Students approaching industrial engineering topics often deal with the design and management of production systems. Typically, students focus on the issues of understanding the problem and modelling the considered system such that alternative solutions can be properly evaluated and selected. Beyond the complexity of techniques and methods that is usually covered with traditional lectures and classworks, students rarely deal with real systems to be observed and modified. The reason is simple, i.e. the unavailability of such real production systems in universities. On the other

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side, real industrial projects are complex and connected to company requirements making the direct involvement of students unfeasible.

Recently, the role of practical experience has gained particular attention in Higher Education [2]. Project activities could help to provide students with a better competence of practical application and problem solving abilities. Several recent works sponsor the introduction of team-based interactive activities for teaching purposes (e.g., games, laboratory experiences). With such experiences, students can develop team-work and organization abilities, apply mathematical knowledge, and grow programming skills.

Herewith, we describe the "LEGO FACTORY" experience, a teaching initiative organized by the Master Degree Study Programme in Mechanical Engineering of Politecnico di Milano. Miniaturized production systems made by LEGO® MINDSTORMS®¹ modules are provided to students who are asked to accomplish a project aiming at the improvement of the system performances. Students from any study course of the university work in cross-sectorial teams on topics they can choose, and present the results achieved at the end of the experience. Hence, students merge different competences and previously acquired knowledge for the resolution of practical engineering problems where finding a feasible working solution, or the proper method to achieve a goal, is often the key activity.

The paper is organized as follows. Section 2 outlines the contributions in the literature about teaching engineering classes with LEGO. Section 3 provides the reader with the basic structure of the physical models used in the course. Section 4 explains the course organization and the learning goals. Section 5 describes the students projects. Section 6 summarizes the lessons learned in this new experience and the concluding remarks.

2. ENGINEERING CLASSES BASED ON LEGO MODELS

The idea of exploiting LEGO as instructional material is based on the belief that effective learning can be established through play [5]. Recently, LEGO MINDSTORMS has been increasingly used as an educational tool for several engineering subjects such as robotics, computer programming, and control. Several applications of LEGO-based systems for teaching purposes can be found in the literature, for example in teaching embedded systems [8], MATLAB coding [1], control theory [9, 4, 13], as well as computer science concepts [10], PID control design [17], model checking [6], and data acquisition [3].

In general, the adoption of LEGO in engineering courses that focus on manufacturing systems is less common. Lugaresi et al. [11] developed a discrete event simulation class in which students can learn the dynamics of a physical system made with LEGO and make experiments with the goal to build the simulation model of the system as project work of the course. Simulation-based decision making to improve the system is also performed. Jang and Josephine [7] developed a flow line consisting in one feeder and two machines with an intermediate buffer. The machines were programmed to simulate failures with different duration. Hence, the system was affected by blocking of the first machine and starvation of the second. The course had three main goals: (1) understanding the processing times and failure rates by collecting data, (2) modeling the system with the objective to optimize the throughput, the cycle time, and work-in-progress, and (3) designing the system in terms of buffer allocation. Thanks to the developed system, students have been able to learn and understand the basic concepts of stochastic modeling, production planning, and scheduling. The authors also showed that the students understanding of the dynamic behavior of manufacturing systems has improved more effectively than with traditional lecture-based learning. Markov-chains have been used as system performance evaluation method. Sanchez and Bucio [15] used a manufacturing system to teach the principles for controlling discrete event systems to postgraduate students and to allow them to gather hands-on experience with an automated system. The physical system was a closed-loop line composed by two workstations, two feeding systems, two dispatchers and a conveyor belt system. The project goal was the design and realization of a hierarchical supervisor for the physical model and capable of executing the production schedule, as well as to design controllers to supervise the resource allocation tasks during production. Syberfeldt [16] designed a practical exercise to teach simulation-optimization to students using a physical factory simulating the refinement of raw materials. The manufacturing system was composed by three stations in line with dedicated controllers. The goal was to provide students an additional tool for learning and understanding simulation-optimization and performance evaluation. Indeed, during

¹ LEGO, the LEGO logo, MINDSTORMS, and EV3 are trademarks and copyrights of the LEGO Group.

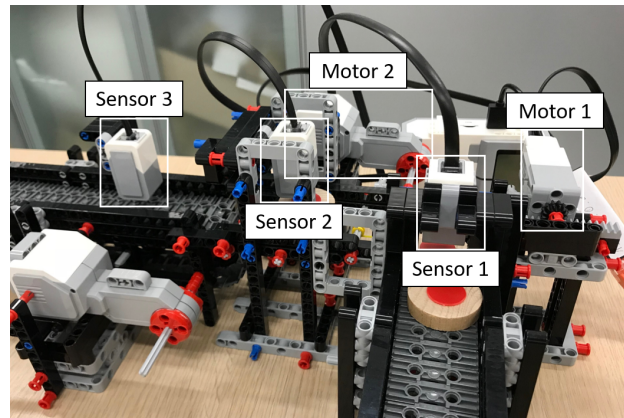


Fig. 1: basic elements of a station in a LEGO Manufacturing System. Sensor 1 detects if a part is queuing at the entrance of the station. Motor 1 lets the parts enter the station one at the time. Motor 2 drives the parts in the station and Sensor 2 detects if a part has entered. Sensor 3 detects if the downstream conveyor has enough slots for the parts to be released.

the project work students were asked to find the best system configuration with the aim of maximizing the profit by changing either the product mix or the buffer capacity allocation along the line. In [14], the authors developed a Computer Integrated Manufacturing environment for the design and assembly of products built with LEGO blocks. The aim was to teach students process planning and trajectory planning software used to determine the production sequence.

To the best of our knowledge, literature about teaching manufacturing systems integration exploiting LEGO is scarce. In this work, we developed a laboratory experience to let students understand the main dynamics and issues that arise when designing and deploying manufacturing systems such as assembly lines, robotic cells, or pallet production lines.

3. LEGO MANUFACTURING SYSTEMS

The laboratory experience is based on the construction of physical models called LEGO Manufacturing System (LMS), namely miniaturised production lines made with LEGO. All the projects aim at building physical models starting from a baseline that allows for compatibility among different models, as well as easy reconfiguration. The basic configuration of an LMS is composed by sequential stations with intermediate conveyors that also operate as buffers. Fig. 1 shows the basic design of a station. All the stations are controlled by EV3 intelligent bricks. Wooden circles tagged with colored plates represent pallets that load the work-pieces. These must be processed by the stations. The processing times are represented by a time interval that each workpiece must wait in a station before being released on the downstream conveyor. Buffer capacities are defined by the position of a sensor on the downstream conveyor of each station, hence the total buffer capacity is limited. The stations are connected to a local network and a PC through Secure Shell Connection (SSH) protocol from which different scripts can be sent to be executed. All the software is written in *python* and exploits the EV3DEV OS and libraries (www.ev3dev.org) to interface with the EV3 hardware.

The LMS has some limits. For instance, with the EV3 sensors it is only possible to detect the pallet presence, while single-piece identification is not achievable. Further, the communication between different devices requires the network design. In order to cope with these lacks, other devices such as Arduino and Raspberry-Pi may be integrated in the system through an IoT software architecture that has been developed for the scope. Additional details about how to build the LMS have been described in [12].

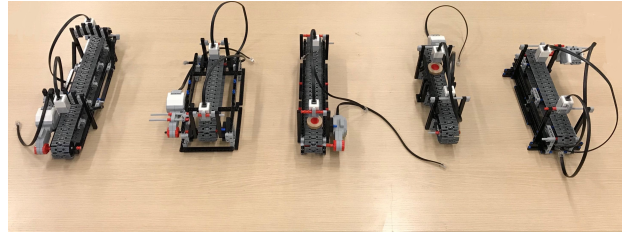


Fig. 2: prototypes of two-station models realized during the introductory class of the first edition of the course.

4. DESCRIPTION OF THE COURSE

The “LEGO FACTORY” course is offered as extra-curricular experience to students come both from Bachelor and Master of Science courses. The participants have been selected to favour diversity among teams. Two editions of the course have been completed, with a total of 56 participants.

4.1. Course Organization

The course is organized in 8 appointments of 4 hours each. Three main activities are included: an introductory tutorial class to get familiar with the course material (both hardware and software), group-work activities with specific requirements, and presentation of results (mid-term and final presentations).

During the introductory tutorial class, the participants are provided with knowledge of: (1) the main elements of integrated manufacturing systems and their relationships; (2) the basic principles of *python* programming language; (3) the basic principles for programming LEGO MINDSTORMS EV3s. In the first class students are also asked to develop a simple prototype of a two-station system. Each station is represented by a sensor and a conveyor brings parts from the first station to the second. Fig. 2 shows the prototypes developed in the first edition of the course. In the group-work activities, students are asked to gather in teams, to choose a project among a set of proposals, and to work autonomously toward the accomplishment of project goals. In the mid-term and final presentation, the teams have to discuss the applicability of their solutions in the integrated system.

4.2. Learning Goals

The “LEGO FACTORY” initiative aims at exploiting the learning-by-playing principles to give students the possibility of understanding the most common issues in the design and management of production systems. The learning goals are not related with the choice of LEGO as hardware.

In the group-work activities, students develop the ability to **handle complexity** of manufacturing systems, to **integrate knowledge** acquired in other courses on productions systems and industrial plants, and to work in a manner that may be largely **self-directed** and/or **autonomous**. Students also develop the ability to **communicate** their choices and conclusions to each other. The group-work activities allow students to:

- Design an integrated manufacturing system in a context of partial information. Students are required to retrieve the rest of information from either external resources or through cooperation among teams.
- Observe the most common issues for designing manufacturing systems (e.g., cycle time constraints).
- Obtain additional soft skills such as the ability to overcome conflicts and critical issues.

5. PROPOSED PROJECTS

The following projects have been successfully completed in the group-work activities of the course:

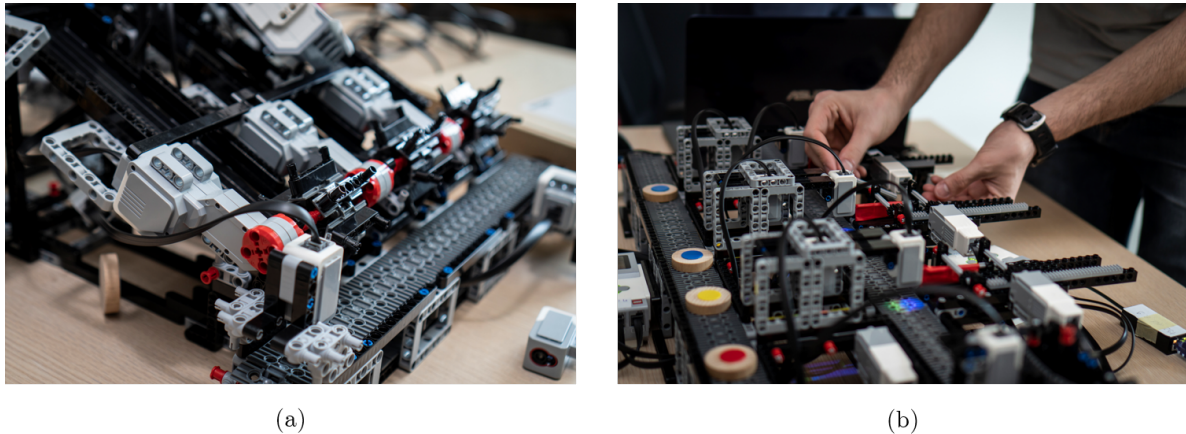


Fig. 3: two projects realized in the course: (a) buffer system allowing load/unload of pallets; (b) manufacturing system with three parallel stations.

1. **Traceability.** Development of a system for tracing parts along the system. The goal is to record the passage of parts along the line and to write a system log file with at least three information labels: part ID, timestamp, and activity ID.
2. **Machine-to-machine Communication.** Development of a distributed control system made of LEGO EV3 modules able to communicate with each other and with a central controller through a local network.
3. **Load/Unload Station.** Realization of a station for loading and unloading the parts from the line and its related management logic. The goal is to be able to decide the sequence of parts flowing in the manufacturing system. Fig. 3a shows the system that has been developed.
4. **Quality.** Construction of a quality control station with its parts re-routing system. The goal is to be able to halt pieces outside the main route to simulate the detection of a bad part.
5. **Robotic Arm.** Development of a material handling system consisting of a robotic arm. The goal is to be able to add and remove pieces from the line.
6. **Guided User Interface.** Development of a software interface for controlling the physical system. The goal is to be able to send commands to the system with a user-friendly interface, so that also people with no programming skills can use the system.
7. **Image Recognition.** Development of an image recognition system able to recognize parts location. The goal is to be able to count the number of parts in a buffer or in the whole system in real-time.
8. **Parallel Machines.** Development of a system able to process parts in parallel. Fig. 3b shows the prototype that has been realized.

At the beginning of each project, students are provided with general specifications. Then, they are encouraged to brainstorm and gather additional information that they need. They may also buy additional hardware within a fixed budget (EUR 100). During the whole course duration, the teams are supervised and provided with technical help.

6. CONCLUDING REMARKS

In this paper, we have presented a LEGO-based learning system. The practical experience facilitates teaching manufacturing systems integration basics. The introduction of this innovative course methodology brought insight on several aspects of the learning experience, both from the students and the teachers perspectives. Following we summarize our thoughts and considerations.

- Several aspects of manufacturing systems integration can emerge autonomously through group work activities. For instance, if several groups are finding solutions to the same problem (e.g., parts movement, sequencing), they have to decide which group will be in charge of a certain operation such as deciding where to position

the sensors. Further, they might encounter design decisions, such as the definition of the pick up point from robotic arm outside the line. Also formalization issues are experienced, such as the decision of which file formats to use.

- Students autonomously recognize the existence of trade-off decisions to be made (e.g., between versatility of movements of a robotic arm and its weight and vibrations). They can understand the importance of the final outcome, hence they are comfortable in criticizing their own solutions in favour for more efficient ones.
- Most of the students are experiencing for the first time in their career working together with teams of people from different ages and diverse background.

In the next editions of the experience, we aim to introduce new projects related to the performance improvement of a system (e.g., productivity, sustainability, profitability). Further, LEGO flexibility will be exploited creating different types of manufacturing systems.

Acknowledgements

This work has been partially funded by *Sme.UP Group* (www.smeup.com) and by the Master Degree Study Programme in Mechanical Engineering of Politecnico di Milano. The Authors also thank Pietro Cattaneo for the pictures of the prototypes.

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