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LEGO Robotics Based Project for Industrial Engineering Education*

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This paper presents the development and implementation of a LEGO robotics based project in an undergraduate- level class on manufacturing systems. In industrial engineering (IE), which includes manufacturing as a major application domain, advanced IT technology and automation science have recently been integrated with manufacturing. As modern manufacturing becomes more complicated and relies increasingly on automation, a new approach is required for IE education. The Department of Industrial and Systems Engineering at Korea Advanced Institute of Science and Technology (KAIST) has developed a LEGO-based Automated Production System (LAPS) design project module for a manufacturing class, using a LEGO robotics kit and MATLAB LEGO support software. In this project, students design and develop an automated production line using LEGO. The aim of the project is to motivate the students to learn about the dynamic flow behavior of production lines and about the design and analysis of manufacturing automation by working through the LAPS design activity. After two years of pilot trials and official implementation in an undergraduate manufacturing class with 32 students, it is found that the LAPS project is significantly effective in motivating students. A survey and class evaluation also shows that students are very satisfied with the class involving the LAPS project. This paper describes how innovations in IE education are possible with new educational technology such as LEGO robotics kits. It also demonstrates how LEGO robotics can be used to effectively teach the dynamic flow behavior of manufacturing systems and how to design manufacturing systems while taking account of this dynamic behavior.

Keywords: project based learning; LEGO based education; LEGO mindstorms; industrial engineering education; manufacturing systems

1. Introduction

The discipline of industrial engineering (IE) traditionally involves scientific decision making, based on data, to increase the efficiency and effectiveness of operations. Industrial engineering is concerned with the analysis, design, and control of large-scale and complex systems comprising people, materials, information, equipment, and money. Examples of such systems are manufacturing plants, transportation systems, and logistics systems.

It is well known that hands-on experience can facilitate the learning of an abstract concept [1, 2]. However, one of the most challenging issues in IE education is the limited opportunities available for students to gain such hands-on experience. This limitation exists mainly because of IE's focus on large-scale systems. The issue can be illustrated by comparing a robot-building project in mechanical or electrical engineering with one in IE. In mechanical or electrical engineering, robot-building projects are commonly used to teach control theory, electro-mechanical system design, system dynamics, or similar topics. Students learn through the process of designing and building a single robot [3–5]. In contrast, IE involves using robots as *components* in a *system*. For instance, in an automated manufacturing system, the production line is the *system* and the industrial robots are the *components* that support the system. The performance of the robots is measured only through the performance of the system as a whole, rather than individually. That is, multiple robots need to coordinate and interact with each other to build products and achieve the goals of the system, such as a target production rate and quality level within a cost constraint.

Ideally, to create a laboratory environment or project for designing such a manufacturing system, a resource for building multiple robots should be provided. Accordingly, the physical scale of the laboratory or project needs to be larger than a project to build a single robot. This characteristic of scale also applies to other domains of IE, such as supply chain management, logistics and transportation, and health care operations, in which multiple resources interact together in a large-scale environment.

It is hard to provide a hands-on laboratory environment or resource for the study of a large-scale system. In the IE curriculum, hands-on experience is sometimes replaced by case studies or simulation experiments. Of course there are benefits and values on the case studies and simulation experiments. However, the benefits of a hands-on experience in a controlled classroom environment cannot readily be provided by alternative modes of study. The benefits of hands-on learning or related study are described in [2, 6–8]. Particularly, hands-

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on experience on manufacturing engineering education has also been addressed in [9–11].

The Department of Industrial and Systems Engineering at KAIST recently created the KAIST LEGO System Laboratory (KLS-Lab). This laboratory provides a design and experimentation environment for use with the LEGO Mindstorms EV3 (hereafter LEGO)—the third generation of the educational LEGO robotics kit—which comprises a LEGO block running under a LINUX OS together with motors, actuators, various sensors, control software, and plastic parts with which to build a mechanical system.

The KLS-Lab enables students to build a system using LEGO for project-based learning. The LEGO-based Automated Production System (LAPS) is a design project module that was developed with the aim of motivating students to learn how the key methodologies in IE help in designing a complex system, through carrying out a design activity using LEGO. The LAPS design project guides teams of students to build a small-scale automated production line using LEGO. Although LEGO robotics has been used educationally in various fields and at various levels [12–15], it has seldom been implemented in IE and manufacturing classes. The LAPS module was developed via multiple pilot runs in Summer 2013, Fall 2013, and Summer 2014. The module was then officially used in an undergraduate class, Manufacturing System Innovation, in Spring 2015. This paper reports on how the LAPS project was developed and implemented in IE education. It describes how innovations in IE education are possible with new educational technology such as LEGO robotics kits. It also demonstrates how LEGO robotics can be used to effectively teach the dynamic flow behavior of manufacturing systems and how to design manufacturing systems while taking account of this dynamic behavior. The movie clips for a system developed by a group of students are shown in [16].

The paper is organized as follows. Section 2 describes previous studies of LEGO robotics based education and explains how our work differs from these studies. Section 3 presents the overview of the LEGO Mindstorms EV3 kit with MATLAB Hardware Support for LEGO Mindstorms EV3. Section 4 explains the details of the LAPS design project module. This section also explains the dynamic behavior of the manufacturing system under uncertainty. Section 5 illustrates the implementation of the LAPS project in the class. Section 6 summarizes the report of the development and use of the LAPS project. This section also discusses the pedagogical implication of the project. The future directions of using the LEGO robotics in IE education are also presented in the section.

2. LEGO-based learning

LEGO robotics has been widely used in multi-level of education. In high school level, Hynes et al. [14] created a LEGO robotics project to train teachers without engineering background in anticipation of the new engineering based curriculum. In the higher education, Gomez et al. [4] designed a special class in response to the increasing demands of mechatronics study. Klassner et al. [5] also designed a LEGO-based course for the Robotic and Computer Science ACM/IEEE Computing Curriculum 2001 [17] for undergraduate students of computer science and electrical engineering. Kim [18] engaged undergraduate students in the Department of Mechanical and Mechatronics Engineering using LEGO Mindstorms in conjunction with MATLAB to help them understand modern control theories. Kim et al. introduced the mapping algorithm control with LEGO robotics to the graduate students of aerospace engineering [19]. Other LEGO-based control and mechatronics classes for undergraduates can be found in [20–23]. There are also reports on LEGO-based projects for general engineering and programming [24, 25].

The existing literature indicates that physical tools and hands-on experience in LEGO robotics based courses improve the quality of learning at different educational levels. It also reveals that LEGO has mainly been used for hands-on projects in the areas of mechatronics and control theory.

However, there is limited literature on using LEGO for manufacturing-related curricula. A project by Sanchez et al. [26] used LEGO as a teaching tool for visualizing an automated manufacturing system. The project gave students insights into how engineers work in practice. Jentsch et al. [27] used a case study involving LEGO Mindstorms to explain knowledge relating to facility planning and system engineering. Lai [28] developed a LEGO-based course for IE undergraduates to teach micro-manufacturing and industrial automation. However, to the best of the author's knowledge, there are no reports on using LEGO robotics to teach the dynamic behavior of production lines and the design of manufacturing systems.

3. LEGO Mindstorms EV3 and MATLAB

LEGO Mindstorms is a series of robotics kits developed by the LEGO Group for educational purposes. The EV3 module is the most recent version of LEGO Mindstorms, released in July 2014. It is known that EV3 has better functionality than its predecessors, the NXT and RCX modules. The LEGO Mindstorms EV3 Education Core Set package comprises one programmable brick, five sensors, three motors as shown in Fig. 1, and several other constructional bricks and elements. This kit was chosen for the LAPS project module because of its modular characteristics and low cost. In addition, the LEGO Mindstorms EV3 kit can be used to easily combine multiple robots and thus build a large-scale and complex system. The details of LEGO parts are described as follows:

- LEGO Intelligent Brick—The intelligent brick is the programmable part of the LEGO Mindstorms EV3 that acts as the computer of the system. The brick works with a small processor and Linux operating system to control all robotic parts of the set. It has four input and four output ports as make it easier to connect with all the sensors and motors. The intelligent brick can be connected to a computer via USB cable, Wi-Fi, or Bluetooth connection for programming. Moreover, the intelligent bricks can be interconnected each other to form a large-scale multiple system.
- Motors—LEGO Mindstorms EV3 provides two types of motors, the large motor with the speed of 160-170 RPM and the medium one with 240–250 RPM. With the command from the brick, these motors can be combined as the main driving force for the various types of system.
- Sensors—Several types of sensors are available from LEGO Mindstorms EV3. The light/color sensor is used to recognize the change in color or light. The ultrasonic sensor can recognize the proximity or send the sound wave to another part of the system. The gyro sensor can measure the degree of the rotation in the moving parts.
- LEGO Technic Building Bricks—LEGO Mindstorms EV3 builds the robot or transportation system with the constructional LEGO technic bricks in the shape of beam, gear, pegs, or other joint component.

MATLAB R2014b, or a higher version, provides a free software package for controlling the LEGO Mindstorms EV3 module via USB cable, Wi-Fi, or Bluetooth. MATLAB contains functions that are compatible with the LEGO brick, sensors, and motor functionalities. Detailed information about the installation and syntax of the MATLAB support software may be found in [29].

4. LEGO-based automated production system (LAPS) design project

4.1 Manufacturing process innovation class

The LAPS design project was first officially implemented in the Manufacturing Process Innovation class, a required class for an Industrial and Systems Engineering major at KAIST. Students mostly take this class during the second year of their undergraduate program. As undergraduate students at KAIST declare their major at the beginning of the first semester of their second undergraduate year, this class is one of the first required classes for the

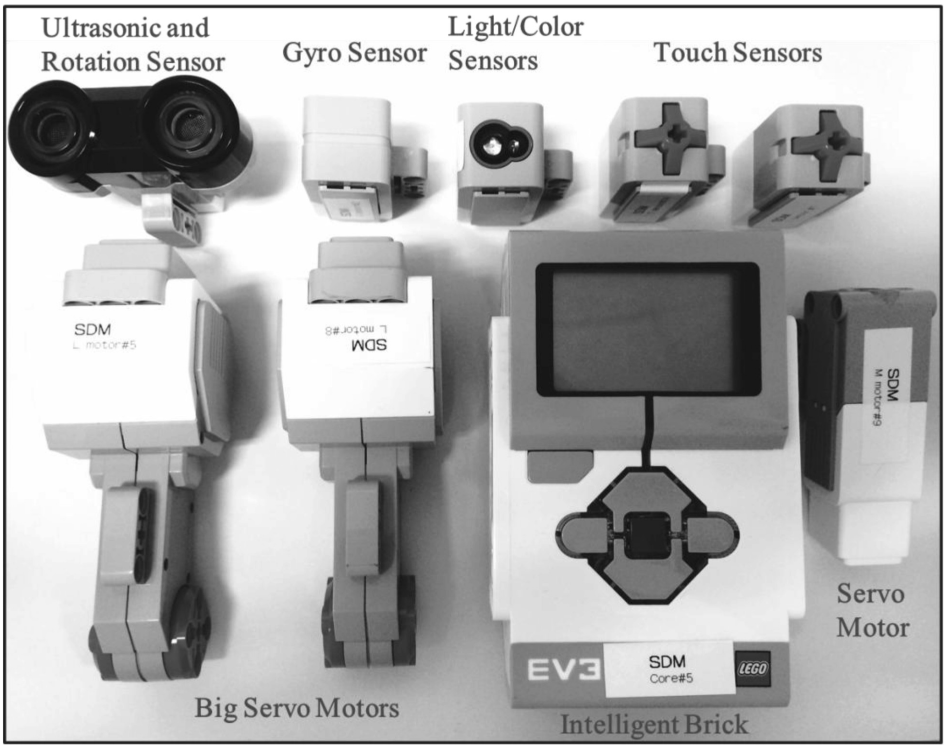

Fig. 1. LEGO Mindstorms EV3 Block, sensors, and motors.

Table 1. Topics in Manufacturing Process Innovation

Topic	Contents
1. Manufacturing system introduction (3 weeks)	Types of manufacturing Basic of manufacturing processes and manufacturing terminologies Performance measures of manufacturing systems—throughput, cycle time, and WIP Overview of the automation systems—AGV, AS/RS, Conveyor, OHT, OHS, etc.
2. Queuing and manufacturing line (3 weeks)	Understanding the random behavior of the line Qualitative analysis of queuing behavior Brief mathematical representation of the randomness in the manufacturing line Simulation experiments
3. Mathematical modeling and optimization (3 weeks)	Fundamental of optimization Trade-off in decision making Brief introduction to linear programming
4. Manufacturing system design (3 weeks)	Production system design overview Considerations in production design Method of designing using a mathematical model and simulation
5. Quality control (3 weeks)	Concept of the quality control in Manufacturing Basic statistical control Design specification and manufacturing quality control

major. Although the name of the class indicates coverage of manufacturing processes, it actually covers manufacturing system design and methodologies in IE in the context of manufacturing. As most of the methodologies in IE were first developed for manufacturing applications, it makes sense to teach these methodologies in a manufacturing context to those experiencing their first exposure to IE. The topics and contents of the class are given in Table 1.

There is no prerequisite for this class. However, students are expected to have an advanced knowledge of calculus, probability, and physics, and basic computer programming skills. Undergraduate students at KAIST take a mandatory fundamental programming class during their first year, and students taking the Manufacturing Process Innovation class are therefore expected to have a basic understanding of and skills in computer programming.

4.2 Dynamic flow behavior in manufacturing systems engineering

Before the LAPS design project is described in detail, the concepts on which the project is based are explained in this subsection. The goal of the project is to enable students to explore some critical systems problems in manufacturing—uncertainty and dynamic behavior arising from the interaction of multiple systems (or components). Some problems arise when several resources are used together to manufacture an item. When such a manufacturing system is created, there is a risk that these resources might interfere with one another. Such resource interference is well explained for the two-machine serial production line described in *Manufacturing Systems Engineering by Stanley B. Gershwin* [30]:

For example, if a part must pass through two machines before it is complete, and one of those machines is down, then the other cannot be used. As a result, some capacity is lost because a perfectly good machine is forced to wait. This can be prevented if some parts have been stored for the operational machine to work on, and there is space to put the pieces it completes while the other is down. In designing such a system one must ask, ''How much space should be allocated for this purpose? and ''How much in-process inventory should be allocated for this purpose?

This is well illustrated with the two-machine-one-buffer production line shown in Fig. 2. The figure shows two processing machines and one buffer. The buffer space is finite. The upstream machine and the downstream machines are denoted by M_1 and M_2 respectively. The buffer between the machines is denoted by B. A part is first processed by M_1 and is then moved to the buffer, B. The part is stored temporarily, then moved to M_2 for further processing. If the processing times of the machines are identical and both machines are up, then the level of parts in the buffer will remain steady. This situation is depicted in the first panel of Fig. 2. However, suppose that M_1 is down. If the failure persists, the number of parts in the buffer will decrease and eventually the buffer will be empty. In this situation, M_2 is forced to be idle even though it is up. This case is presented in the second panel of Fig. 2. Then suppose that M_2 is down instead. In this case, the number of parts in B will increase and will eventually fill the buffer. M_1 will become blocked and will be forced to be idle even though it is up. This case is illustrated in the third panel of the figure.

In manufacturing systems engineering, instances of blockage and starvation are called interruption of flow. One way to lessen the interruption of flow is to

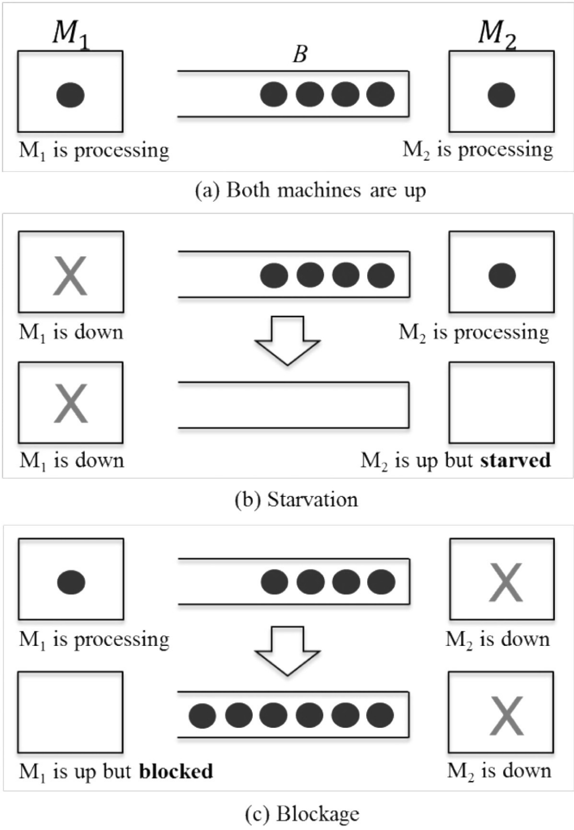

Fig. 2. Two-machine-one-buffer manufacturing line—two-machine operations, starvation, and blockage.

increase the size of the buffer. If there is no buffer at all, the starvation or blockage of one machine will directly affect the other machine. However, if there are parts stored in the buffer, the effect of the starvation or blockage will be reduced. Therefore, the buffer is acting to dampen the interruption of flow. However, a large buffer is more costly in practice. More space on the factory floor is required to provide a larger buffer space. In addition, more buffer space could lead to more parts existing (a larger work-in-progress inventory). More parts in the buffer can also increase the cycle time, which is the length of time that a part is in the system. A good analogy is that more people waiting in line for the cashier in a store could lead to more time waiting in the line.

Note that the production line described above consists of two machines and one buffer. Although each machine and the buffer have their own design parameters, such as processing time, probability of failure and repair, and buffer size, the overall performance of the line is a result of a complex interaction between the components.

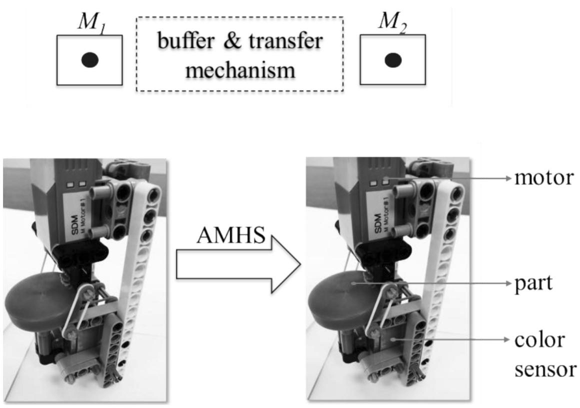

Fig. 3. Processing machine as supplied to the students, and the AMHS part that the students need to design.

4.3 LAPS design project module

In the LAPS design project, students are required to build a two-machine-one-buffer production line using LEGO. Specifically, the students create the physical system that is presented theoretically in [30]. This two- machine-one-buffer production line was chosen for the project due to its substantial pedagogical value. The system exhibits the dynamic flow behavior that occurs in actual manufacturing lines. Students will learn about this important flow behavior in manufacturing by working through the design activity.

In the initial introduction to the LAPS design project, the students are given no explanation of the dynamic flow behavior. Instead, the students are expected to learn about this system behavior through carrying out the design activity within the project. They learn directly about the dynamic behavior of manufacturing systems and understand indirectly the need for the key methodologies of IE, and thus are motivated to appreciate the value of IE.

The project module is designed to be performed by a group of 3–4 students majoring in IE, and to take about 30 hours altogether to complete. The target student group is undergraduate students at an early stage in the study of their major.

4.3.1 AMHS development

The main task in the project is to build a production line using LEGO. Specifically, the students build a production line comprising two machines with an AMHS that connects the machines. It should be noted that the abstract system shown in Fig. 2 does not contain an AMHS that delivers parts. However, in an actual system an automated system is required to move the parts.

Instead of asking students to build the entire production line from scratch, a pair of subsystems, the processing machines shown in Fig. 3, are pre-assembled and provided for the students. The students' primary task is therefore to build an AMHS to transfer parts between the two machines provided.

Building an AMHS requires certain depth of engineering decision making and logical thought processes. Due to the machines' pre-programmed random behavior, each element of the AMHS should be coordinated carefully to transfer the parts. It cannot send a part when the downstream machine is processing or down, also, whenever the upstream machine completes the processing a part, the AMHS needs to receive the parts. This coordination is the key in designing the system.

Each machine comprises a small motor, a light sensor, and a feeder made from a rubber band and gear components. The students are also given some circular chips, which represent the parts to be transferred. The processing machine takes a part using the feeder powered by the motor. It holds the part for a while, to imitate processing of the part, then pushes the part out. A color sensor directly below the machine detects whether a part is loaded on the machine.

The requirements for the AMHS to be designed are that the processing machines have to be at least 20 cm apart and must be located on a flat base at the same height. As long as the first machine is empty and ready to process, a part is inserted manually. The part must then be automatically transported by the AMHS and loaded into the second machine.

We provide pre-assembled machines and ask students to build only the AMHS for the following reasons. First, designing the AMHS is sufficient for achieving the goal of the project—that the students will understand the dynamic behavior of the production line by working through the design process. There are three major subsystems—two machines and the AMHS. The AMHS is not merely a delivery unit for parts; it coordinates the dynamics of the two machines. We want the students to understand the dynamics of this system through the process of designing the AMHS. Second, we wish to manage the design project to a certain degree. Students are given a clear direction and the goal of the project—to design an AMHS to transfer parts between two machines. We had learned from the pilot classes that having the students build only the AMHS for given machines was sufficient to achieve the pedagogical goal.

4.3.2 Project evaluation

After the students have completed their design, they must demonstrate their system and give a presentation to explain how they built it and the underlying reasons. That is, performance in the project activity is measured through this demonstration run and presentation. In the demonstration, 100 parts are inserted into the system and it is evaluated. The specific evaluation criteria are given as follows:

- Functionality—The AMHS should deliver the parts whenever the machines are ready to process—if the system cannot complete processing 100 parts caused by any hardware malfunction or software error, evaluation points are deducted proportional to the parts the system could not complete the process. For example, the system completes the 80 parts but a hardware malfunction occurs at the 81st part, the 80% of the points on this category is given.
- Productivity—The amount of time the designed system completes the 100 parts is measured and throughput is evaluated: (*total number of parts*) (*total time to produce the parts*). There is a theoretical maximum production rate and the production rate from the designed system is compared and the evaluation points on this criteria is calculated as following :[(*theoretical maximum throughput*) – (*system's throughput*)] (*theoretical maximum throughput*) $\times$ 100.
- Cost—The bigger the size of the AMHS is, the higher the cost; that is if more parts are used, more cost penalty is given in the evaluation.

Students also need to deliver the presentation explaining a logical thought process of the design. The presentation evaluation is composed of the idea, analysis, and representation parts. The evaluation questions are as follows:

- Is the design creative?
- Do they have logical reasons for their proposed design?
- Do they understand the trade-off relationship between the production rate and the buffer size?
- Do they understand the function of the AMHS and how the impact of the randomness can be mediated by the AMHS?
- Is the presentation clearly delivering their system and idea?

Each question is measured on a scale of 1 (strongly disagree) to 5 (strongly agree). The first question is about the creativity of the design and the last question is about the communication and representation of the idea. The rest of the questions are about the analysis and logical thought process. The second question asks how they come up with specific hardware design and software logic. For example, suppose that students design a conveyor belt, then they are asked why the conveyor belt is running at the designed speed or why the length of the conveyor belt is as designed. Specific parameter related questions are asked. The second and third questions are asked in order to find if students understood the system issues described in Section 4.2. Students do not need to perform any qualitative analysis, however they need to explain the system with qualitative reasoning in their presentation.

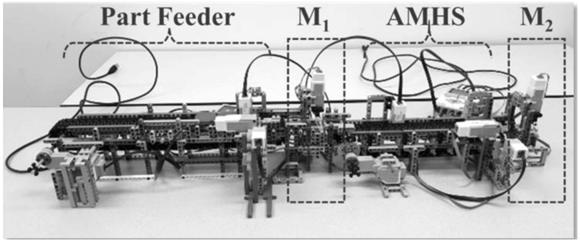

Fig. 4. Two-machine-one-buffer production system built by a student group.

5. Class assessment

The class in Spring 2015 comprised 32 undergraduate students, and they were divided into 8 groups. Each group had to complete the project within 6 weeks. After the sixth week, each group gave its demonstration and presentation. This revealed that most of the students understood the dynamic flow behavior and design considerations of the production system. They also understood the trade-off between production rate and buffer size.

Figure 4 shows the system designed by one of the groups. Note that the system in Fig. 4 includes the part feeder student designed. This feeding mechanism controls the input parts into the system. Students in the group discovered that the part waiting time was determined by the input rate of the parts and therefore they had also created the feeder. This finding was actually true and there was a theory behind this discovery. The students discovered this behavior by themselves and implemented the mechanism in their system.

No significant differences between the results for the Fall 2012 and the Spring 2015 classes are seen for the non-project-related quizzes (Quiz No. 1 and 2) but a significant improvement is evident for the project-related quizzes (Quiz No. 3 and 4)

To assess the effectiveness of the project in terms of improving the level of understanding of the students, we compared the test results with those from a class offered previously. The same class, Manufacturing Process Innovation, offered in Fall 2012, was selected as the reference class. The LAPS design project was developed from 2013 onwards with pilot testing in several different classes. The class offered in Fall 2012 was the last class taught without a LEGO project. This class was taught by one of the authors with otherwise identical content.

It should be noted that there were 68 undergraduate students in the Fall 2012 class and 32 in the Spring 2015 class.

This difference arose from the class being available in both the Spring and the Fall semesters each year from 2015, compared with a single class in the Fall semester before 2015. As a result, differences due to the number of students should be factored in when the classes are compared.

To identify the effectiveness of learning, four quizzes completed by the Fall 2012 class throughout the semester were also given to the students in the Spring 2015 class. The first two quizzes covered the quality and physical processes of manufacturing, which were not directly related to the LAPS project (non-project-related quizzes), while the others covered topics related to the LAPS project (project-related quizzes). A comparison of the results obtained from the quizzes is shown in Table 2 and Fig. 5. Quizzes 1 and 2 are "non-project-related quizzes" and Quizzes 3 and 4 are "project-related quizzes." Table 2 lists the mean, standard deviation of the mean, minimum, maximum, and median of the scores for each quiz. Fig. 5 shows the box plots for the results. No significant differences between the results for the Fall 2012 and the Spring 2015

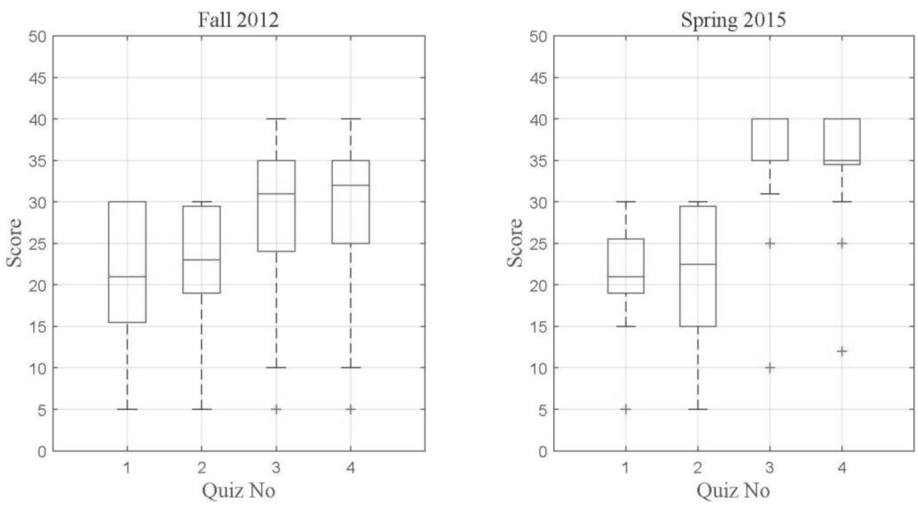

Fig. 5. Exam result comparison.

Table 2. Test Result. The lists of the mean, standard deviation of the mean, minimum, maximum, and median of the scores for each quiz

	Fall 2012				Spring 2015			
Quiz No	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Mean	21.62	22.74	28.15	29.96	22.03	21.31	36.59	35.25
Std	7.72	6.78	9.09	8.98	6.86	7.37	6.02	6.38
Max	30	30	40	40	30	30	40	40
Min	5	5	5	5	5	5	10	12
Median	21	23	31	32	21	22.5	40	35

Table 3. Course Evaluation. The results of an overall course evaluation performed by KAIST—the class evaluation report gives overall class scores on a scale of 1 (not satisfied at all) to 5 (highly satisfied)

	Fall 2012				Spring 2015			
	Undergraduate enrollment	**Respondent**	**Average**	**Std. dev.**	**Undergraduate enrollment**	**Respondent**	**Average**	**Std. dev.**
Overall	32286	27351	4.19	0.83	32137	25948	4.18	0.82
Department	934	795	4.12	0.89	777	633	4.24	0.83
Course	68	64	3.99	0.84	32	30	4.41	0.79

classes are seen for the non-project-related quizzes. It can thus be conjectured that the students in both classes were at a similar educational level. In contrast, a significant improvement is evident for the project-related quizzes 3 and 4. The results indicate that the project had a positive effect on the level of understanding.

Table 3 shows the results of an overall course evaluation performed by KAIST. The class evaluation report gives overall class scores on a scale of 1 (not satisfied at all) to 5 (highly satisfied). The score for each class is also compared with the average scores of all of the classes offered by KAIST and of the classes offered in the same department, so that instructors are able to understand the scores of their classes relative to other classes.

Table 3 reveals the detailed metrics of the level of satisfaction with the Fall 2012 and Spring 2015 classes. The satisfaction score for the Fall 2012 class is 3.99, which is lower than the average scores for the department and the institution as a whole. In contrast, the satisfaction score for the Spring 2015 class is significantly increased, at 4.41, and is higher than the average scores for the department and institution as a whole. A significant improvement in the satisfaction score is thus observed.

An anonymous survey specifically covering the project was also conducted separately at the end of the semester. Of the 32 students, 27 completed the survey. The results are shown in Table 4. In summary, most of the students had positive feelings about the effectiveness of the project in terms of their understanding. Most of the students were satisfied with the project.

6. Conclusions

In short, the LEGO-based project was effective in motivating students. The feedback obtained was positive and the students found the subject very interesting. Moreover, the test results indicated that the students were able to understand the issue of the dynamic flow behavior of manufacturing systems more effectively than with traditional lecture-based learning. The results of the survey and the class evaluation also showed that the students were highly satisfied with the class involving the LEGO-based project module. Although the module has only been used in one entry-level IE major class, it can also be used in other IE classes. In addition, LEGO robotics does not necessarily have to be used as a design project; it could also be used as an experimental device.

Specifically, for example, the LEGO based automated stocking and retrieval system (AS/RS) has been built as shown in Fig. 6. This system will be used in Manufacturing Systems Engineering class, one of the graduate level classes offered in the department, in the near future. In this graduate level class, students will perform various data collections and analysis to identify the needs of the improvement on the system. That is, they will not build something, but instead they will investigate and analyze the AS/RS system as if they were factory managers/engineers continuously trying to improve the existing system. For this case, instead of designing and building something new, they will analyze the existing system and come up with an idea to make an improvement. This LEGO AS/RS system will provide this experimental environment at low cost.

Another application of the LEGO system might

Table 4. Project Survey. The survey results conducted for the project at the end of the semester (27 out of the 32 students completed the survey)

No	Question	Response
1	The LAPS project helped understand the dynamic behavior issues in manufacturing (scale 1—strongly disagree to 5—strongly agree)	4.3
2	You are satisfied with the group members in your group (scale 1—strongly disagree to 5—strongly agree)	3.1
3	Rate the overall satisfaction level of the project (scale 1—very unsatisfied to 5 very satisfied)	4.1
4	How many hours did you spend on the project	37.5
5	What is the most difficult part in the project: • (1) Concept design • (2) MATLAB programming • (3) Hardware build • (4) System tuning	 • (1) for 53% • (2) for 0% • (3) for 21% • (4) for 22%
6	What is the type of skill do you think you need most for the design of LAPS (describe)	• Extra support for the hardware design • Design process method • system modeling and simulation to select parameters
7	What thing can be improved in the LAPS in the future	• More project hours and example cases
8	Other comments	• I could learn from other students • 5 weeks were too short and more time is needed • I now understand why the methodologies are needed • Team interaction and leadership training are needed • It would be better to do the project after we learn some analytical methods • Simulation • It was interesting to know how the randomness can be reduced with a good buffer design

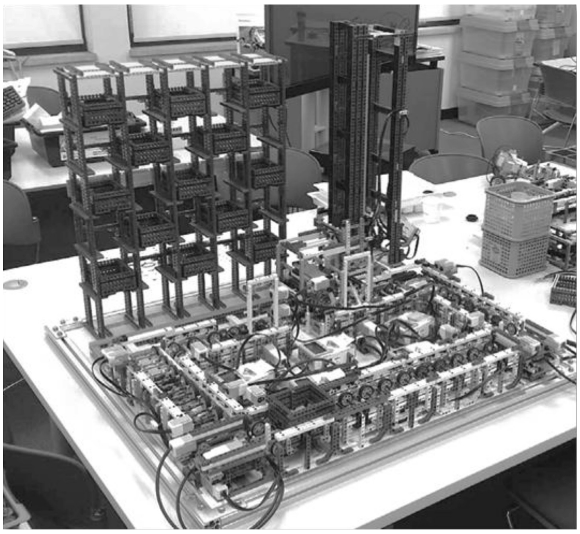

Fig. 6. Automated warehouse stocking (AS/RS) system made out of LEGO Mindstorms EV3.

be to demonstrate the concept of the Internet of Things (IoT) and smart factories. The intelligent brick which runs with Linux OS and the sensors can be worked as a smart sensor. The multiple bricks can communicate wirelessly and create a sensor network. Applying LEGO-based systems to IoT and smart factories is currently under investigation.

Finally, it would be interesting to explore the possibility of using the LEGO system for data mining. A significant amount of log data is generated in real time by the LEGO system. Sensor data and actuator data combined with the physical movement of the LEGO system can provide an excellent platform for data mining. Given that acquiring real data for classroom use is difficult, a physical system such as that shown in Fig. 4 can be used to generate data. Additionally, the LEGO robotics based system is not limited to use in IE education. It could be used in business and management areas such as Operations Management, Supply Chain Management, and Mathematics for Managers to teach about operational issues or business problems, opportunity identification issues, or business process design.

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