AC 2008-105: USING LEGO TO TEACH AND LEARN MICROMANUFACTURING AND INDUSTRIAL AUTOMATION

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Abstract

This paper describes the design and evaluation of two laboratory experiments that introduce LEGO® Digital Designer and MINDSTROMS® Education systems as meaningful means to reinforce concepts of micromanufacturing and industrial automation to engineering undergraduate students. The proposed laboratory experiments aim to complement the classroom lectures and to increase students' conceptual understanding and learning motivation. The first laboratory experiment introduces the LEGO Digital Designer as a 3D design program to better understand the micromanufacturing process through the virtual assembly of LEGO blocks. The second laboratory experiment uses LEGO Mindstorms NXT systems to provide students with hands-on team projects to design and build an automated system while applying concepts learned in the classroom. Data from students' projects and surveys is presented to evaluate the efficacy of the designed laboratory experiments on student engagement and conceptual understanding.

1. Introduction

Concepts in manufacturing can be very challenging for engineering students to understand in classroom lectures alone. This paper focuses on two particular areas of manufacturing: micromanufacturing and industrial automation. In micromanufacturing, the layer-by-layer manufacturing process for microdevices becomes a challenge for students to understand how these devices can actually be fabricated. In industrial automation, challenges in designing a control system can only be experienced by implementing an actual control system for a physical device or system. Therefore, it is necessary to provide students with relevant hands-on experiences to reinforce the material learned in the class lectures and to generate interest in these fields.

Active learning approaches are essential for college students to apply the material learned in the classroom and to stimulate their understanding, motivation, and creativity. Research in the adoption of active learning techniques in engineering courses has demonstrated several benefits to student learning outcomes such as increased student engagement, increased student retention of material, and increased conceptual understanding [2-4, 9]. Providing active learning experiences is always a challenge for instructors requiring significant amounts of time, materials, and funding [6]. In universities, LEGO kits have been successfully applied as a convenient and cost-effective active learning approach for prototyping designs, robotics, data acquisition, and chemical engineering problems [5-8, 10, 11].

The LEGO® MINDSTROMS® Education system has recently launched the latest version of its LEGO systems called LEGO Mindstorms NXT, which contains a variety of pieces such as gears, motors and sensors to build and control vehicles, robots, and systems. It contains a programmable microcontroller called the *NXT Intelligent brick* that can be easily programmed using a software environment called LEGO Mindstorms NXT to control the students' mechanical designs. Little programming experience and technical support is required so it is easy for students to use. In addition to the LEGO systems, LEGO has launched a free 3D modeling and building system called LEGO Digital Designer that allows users to virtually build 3D design models using a variety of LEGO blocks. This 3D design program can further enhance the learning experience of students by providing meaningful hands-on activities.

This paper describes the introduction of LEGO Digital Designer and LEGO systems in Industrial Engineering courses to teach concepts in manufacturing, in particular micromanufacturing and industrial automation. Two laboratory experiments were designed and implemented in two different courses offered through the Industrial & Management Systems Engineering (IMSE) department at the University of South Florida. The first laboratory experiment uses the LEGO Digital Designer as a new approach to teach students the fabrication steps for creating microstructures. The second laboratory experiment introduces LEGO systems to enable the students to design, build, and control their own automated systems while applying concepts learned in the classroom lectures. This paper also presents the results from students' projects and evaluations assessing the efficacy of the proposed approach on student conceptual understanding and learning motivation.

2. Methods

The objective of this paper is to incorporate LEGO 3D design programs and systems in undergraduate industrial engineering courses to provide students with hands-on team lab activities that will help them better understand the challenging principles of micromanufacturing and industrial automation. These hands-on team activities were designed to achieve the following pedagogical objectives:

a) Increase student conceptual understanding by integrating theory with practice using LEGO 3D programs and systems
b) Development of personal skills such as communications, technical writing and team working skills
c) Increase student engagement through meaningful and fun activities

The LEGO Digital Designer and Mindstorms systems were applied to two undergraduate courses in the IMSE department: Manufacturing Processes (EIN 4411) offered in the Fall 2006 semester and Automation and Robotics (EIN 4621), which was offered in the Spring 2007 semester. Each course consists of 2 hours of lecture and 2 hours of laboratory per week. The class size in these courses was 30 and 25 students, respectively. For each course, three laboratory sessions were offered per week with each session consisting of a maximum of 11 students. The majority of the students were from the IMSE department and there were also students from the departments of Mechanical Engineering and Civil Engineering.

The lectures for the Manufacturing Processes and Automation and Robotics courses were revised to incorporate topics on micromanufacturing and control systems, respectively. These lectures were designed to introduce students to the topics in the classroom prior to performing the activities in the lab session. The following sections describe the design of the laboratories:

2.1 LEGO-Based Micromanufacturing Laboratory Exercise

A new 3D design program called *LEGO Digital Designer* was introduced in the Manufacturing Processes course to reinforce concepts of micromanufacturing to engineering undergraduate students. As shown in Figure 1, LEGO Digital Designer is a free 3D modeling and building system that allows students to virtually build their own designs using a variety of LEGO blocks. Through the computer, students can select and drag a variety of LEGO blocks and create any design they can imagine.

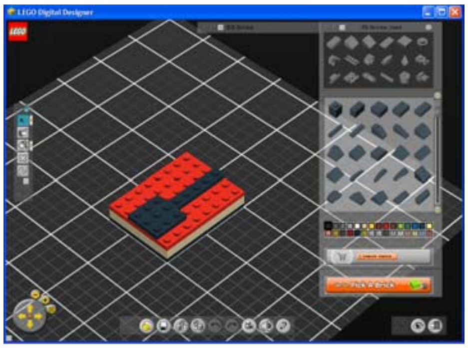


Figure 1. LEGO Digital Designer Graphical Interface

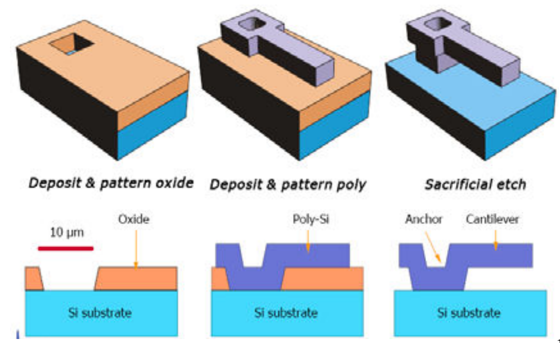
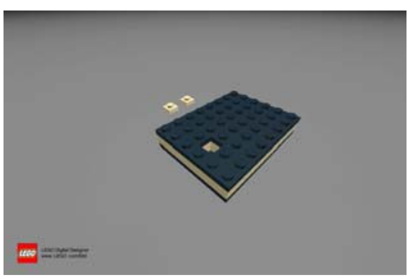
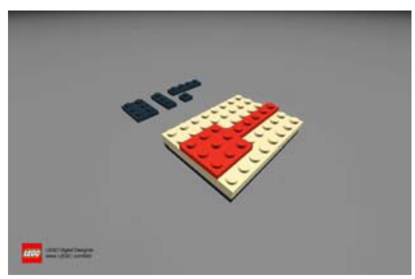


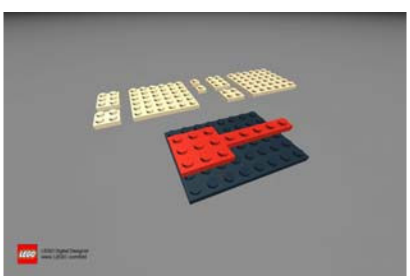
Figure 2. Steps in surface micromachining [1]



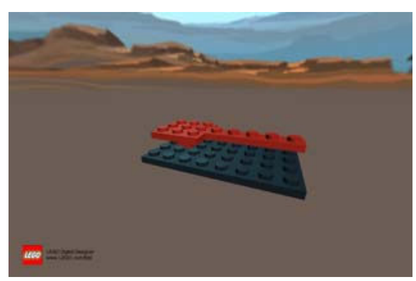
(a) Deposit and pattern oxide



(b) Deposit and pattern poly



(c) Sacrificial etch



(d) Final structure

Figure 3. Lab exercise for micromanufacturing using LEGO Digital Designer

For the micromanufacturing lab exercise, the manufacturing process covered was *surface micromachining*, which is a layer-by-layer fabrication process used to construct cantilevers, overhangs, and similar structures on a silicon substrate. Figure 2 shows the steps for surface micromachining to create a micro-electro-mechanical system (MEMS) cantilever, which was covered in the class lecture. The class lecture also covered examples and applications of MEMS created by research groups and research agencies such as the Defense Advanced Research Projects Agency (DARPA). The lab exercise for micromanufacturing consisted on using the LEGO Digital Designer program to recreate each step of surface micromachining using virtual LEGO blocks as shown in Figure 3. A tutorial was developed for the LEGO Digital Designer with step-by-step instructions and illustrations on how to use the program. The tutorial also guided the students through the process where the different LEGO block colors represent the different layers used in surface micromachining.

An introduction at the beginning of the lab exercise was provided to remind students about the material covered in the class lecture and the relationship to the lab exercise. Instructions were also provided to familiarize students with the LEGO Digital Designer user graphical interface. Each student worked on the lab exercise individually to obtain hands-on experience using the program. Once the student finished the lab exercise, a lab report was requested in teams of two to three students. The report consisted on the objective of the lab exercise, a description of surface micromachining, lab exercise procedure, and results and illustrations. Each team of students were also required to perform a search on the internet and books for information regarding the specific microstructure created through the LEGO Digital Designer and the specific manufacturing process covered in the lab session.

2.2 LEGO-Based Industrial Automation Laboratory Exercise

LEGO Mindstorms NXT systems were introduced in the Automation and Robotics course to provide students with a hands-on team course project that required the use of concepts learned in the classroom throughout the semester. The LEGO Mindstorms NXT system and software includes 431 elements including motors, sensors (light, sound, ultrasonic, touch, rotation), and a NXT Intelligent brick, which is used to download the program to control the device. In this paper, we will refer to the LEGO Mindstorms NXT system as the LEGO system.

During the course lectures, concepts and applications of robotics and automation were covered including control and programming. In the middle of the semester, students were assigned the course project that they will be working in teams of 2 to 3 students until the end of the semester. The course project consisted of designing, building, and implementing an automated guided vehicle (AGV) that will be used in a manufacturing plant to transport material from one place to another. The team needed to use the LEGO system set and its software to build and design the control system for the AGV. The AGV was required to achieve the following tasks:

a) The AGV starts at an initial location (manufacturing cell *A*) and moves to a second location (manufacturing cell *B*) to pick up an object (wooden block). The AGV must follow a fixed trajectory indicated on the floor to go from manufacturing cell *A* to *B*. The trajectory for the AGV was specified in the laboratory and represents the fixed path for the AGV within the manufacturing plant.
b) Once the AGV arrives to manufacturing cell *B*, it should stop and wait until the object is placed on the AGV. The AGV should detect the presence of the object and begin transporting the object back to manufacturing cell *A* following the path.

c) During the trajectory, the AGV should not collide with any other elements in the environment since this will cause damage to the AGV, manufacturing equipment and building.
d) Once the AGV returns to manufacturing cell *A*, it should stop and wait until the object is removed from the AGV.

An introductory lab session was provided to the students to introduce them to the LEGO system software. Teams of students worked during the second half of the semester on their project designing and building their own AGV and the corresponding control system to successfully accomplish the tasks as shown in Figure 4. Figure 5 shows an example of one of the teams AGV developed using LEGO elements such as motors and sensors. Students had to take into account the design of the AGV, particularly the structure that carries the wooden block, so that the block would remain in the AGV without falling while simultaneously activating the touch sensor. Students also had to solve the problem of implementing the control system so that the AGV achieves the specified tasks.

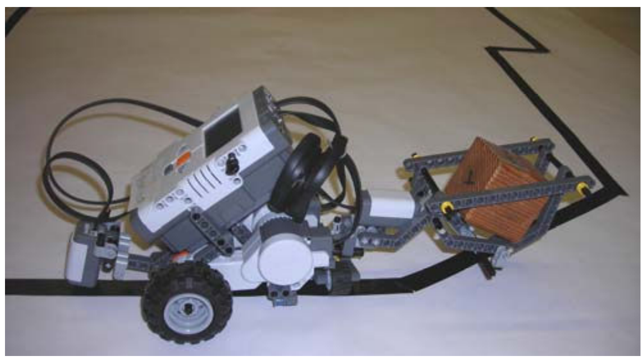


Figure 4. Automated Guided Vehicle (AGV) design from one team of students

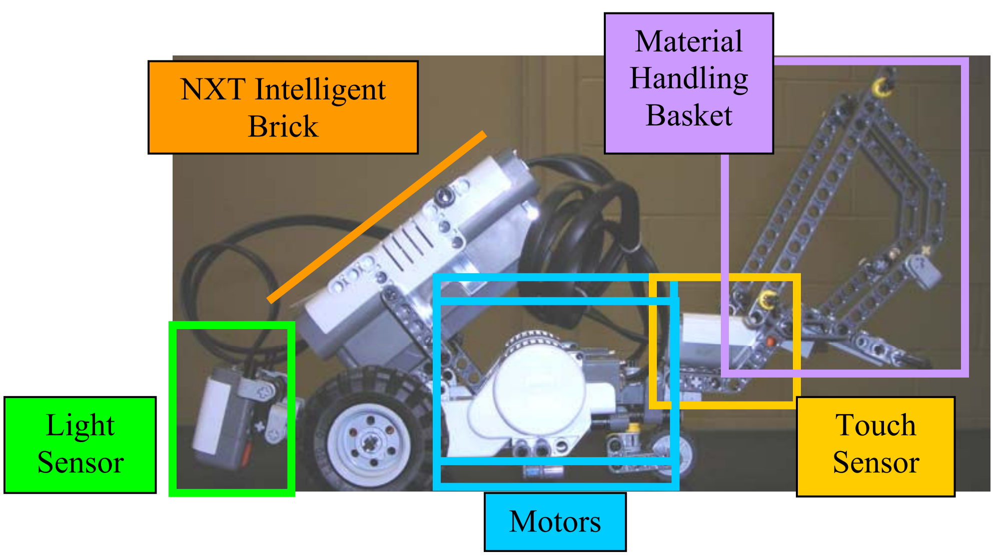


Figure 5. Components of the AGV using LEGO Mindstorms NXT systems

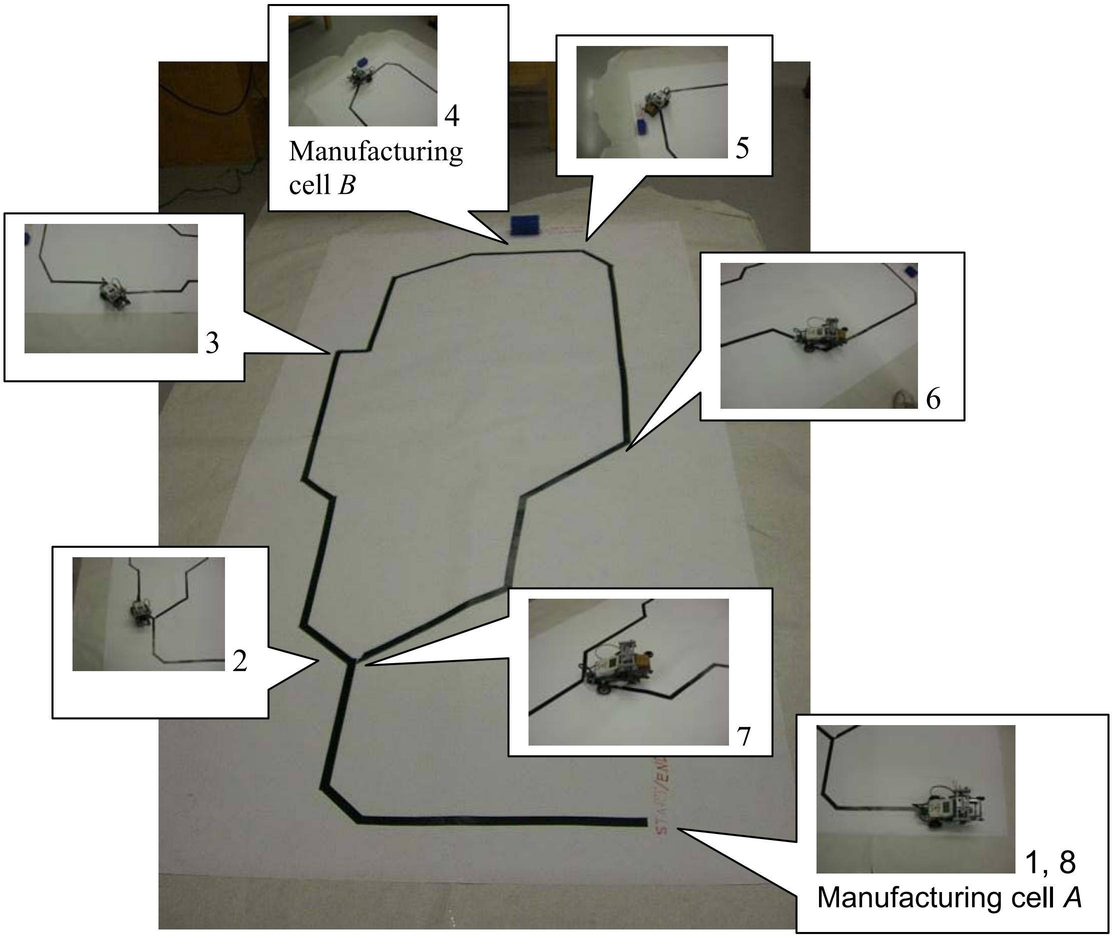


Figure 6. AGV path for transporting material and AGV performing the tasks

At the end of the semester, each team submitted a project report consisting of the project description, their AGV design, control system, timetable for completion of the AGV, and results and illustrations. Each team gave an oral presentation of their project and a demonstration of their AGV achieving the specified tasks as shown in Figure 6.

3.   Results and Discussion

At the end of each lab exercise, a lab evaluation form was provided to each student to collect data regarding the easiness and effectiveness of the LEGO Digital Designer and systems in both courses. Questions were provided in the lab evaluation and the students rated each question from 1 to 5 being 1 the lowest and 5 the highest mark. The results and discussion for each laboratory exercise are described in the following sections:

3.1 Results for the Micromanufacturing Laboratory Exercise

For the micromanufacturing lab exercise using the LEGO Digital Designer, the data and results are shown in Table I.

Table I. Results from students' evaluations on the micromanufacturing lab exercise

Question	Average (scale 1-5)
1. The LEGO lab was interesting	4.3
2. The LEGO lab was fun	4.5
3. The LEGO lab was educational	4.0
4. Do you know more about micromanufacturing than before the lab?	3.4
5. Did this lab help you understand micromanufacturing better?	3.8
6. Did this lab motivate you to learn more about micromanufacturing?	3.8
7. The lab tutorial was easy to follow	4.5
8. How difficult was to learn the software?	2.3
9. Would you recommend other to take the LEGO lab?	4.1
10. Overall, how would you rate the lab?	4.3

Table I shows that the students found the laboratory using LEGO Digital Designer interesting, fun and educational. The developed tutorial was easy to follow although some students suggested that the tutorial would be clearer if printed in colors as the different layers are difficult to distinguish in black and white. Students found the 3D design program easy to learn. Most students found that the labs helped them to understand micromanufacturing better and some suggested having more lab exercises using the LEGO Digital Designer. Some of the students comments are as follows: "I understood how cantilever MEMS were created before, but 'building' it myself solidifies what I understood previously", "I love the software, it's very interactive, colorful, so it catches my attention", "I liked this lab!". Overall, students rated the lab very high and they would recommend it to other students.

3.2 Results for the Industrial Automation Laboratory Exercise

The results for the laboratory exercise on applying LEGO Mindstorms systems for learning industrial automation are shown in Table II.

Table II. Results from students' evaluations on the industrial automation lab exercise

Question	Average (scale 1-5)
1. I found the LEGO project to be challenging	3.5
2. I found the LEGO project to be fun	4.3
3. The LEGO project was effective in helping me understand and apply problem solving techniques	4.1
4. The project helped me understand industrial automation better	4.1
5. I thought that building our LEGO AGV provided an effective way to learn to work in a team	4.1
6. How difficult was to learn the LEGO Mindstorms NXT software?	3.1
7. My enthusiasm to study automation and robotics has increased due to the LEGO project	4.0
8. Overall, how would you rate the LEGO project?	4.3

As shown in Table II, students found the LEGO project to be fun and effective in helping them understand concepts and apply problem solving techniques. They also found that the project helped them understand industrial automation better and was an effective way to learn to work in a team. However, they found the project average on the challenging aspect. Some of them suggested to incorporate more sensors and to make the project more complex. This is due to the limitation on the number of sensors and motors that the LEGO Mindstorms systems currently offer. Future work will address the increase in complexity for the course project through the incorporation of more components and tasks. The LEGO Mindstorms NXT software was not difficult to learn but some students suggested that a more detailed explanation of the software would be helpful. Some of the students' comments are as follows: "It was a fun project", "I enjoyed the hands on, and having to use problem solving to fix the Lego when it didn't work", and "I liked it". Overall, the students rated the LEGO project very high and found the project to increase their enthusiasm to study automation and robotics.

4. Conclusions and Future Work

This paper describes the design and evaluation of two laboratory exercises using LEGO Digital Designer and Mindstorms systems to provide hands-on activities to undergraduate students that facilitate the conceptual understanding of micromanufacturing and industrial automation concepts. Results from students' projects and evaluations show that the designed laboratory exercises can increase students' understanding of manufacturing and industrial automation concepts while increasing their learning motivation. The designed activities also promoted the development of problem solving, teamwork and communication skills. Future work will focus on enhancing the tutorials for clarity and on incorporating more components for more complex tasks for the course project. An additional lab session will be incorporated to introduce students to the computer program prior to the start of the project to facilitate student learning of the new software.

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