A first introduction to programming for first-year students at a Chinese university using LEGO MindStorms

Hai-Ning Liang, Charles Fleming, Ka Lok Man
Department of Computer Science and Software Engineering
Xi'an Jiaotong-Liverpool University
Suzhou, China
{haining.liang, Charles.fleming, ka.man}@xjtlu.edu.cn

Tammam Tillo
Department of Electrical and Electronic Engineering
Xi'an Jiaotong-Liverpool University
Suzhou, China
tammam.tillo@xjtlu.edu.cn

***Abstract*—In this paper, we describe some of our experiences in incorporating LEGO MindStorms into an introductory programming course. There are three distinguishing features of this course. First, it had a large number of students; almost 500 students were enrolled in it and most of them had minimal to no exposure to programming before taking the course. Second, it is taught at a Sino-British university but located in China—that is, the lessons were given in English and the curriculum met both the UK and Chinese standards. Third, the students had varied interests, ranging from engineering to computer science to industrial design. The experiences described in this paper will be useful to educators who are planning to integrate LEGO MindStorms into their teaching of programming to novice students who are from different backgrounds and with varied interests, enrolled in a large class, and who attend a university outside of developed countries.**

Keywords—Introductory programming; CS0/CS1 teaching; computer science and engineering education; LEGO MindStorms; collaborative/group learning.

I. Introduction

Computer programming was introduced in China in the 80s in high schools [21] but it is still not part of the main curriculum. Entry to universities is based on the results of a nationwide standardized exam which does not including programming. This means that except for very few cases Chinese students have minimal to no knowledge of programming when they go to university. In addition to computer science students, students from engineering and related fields, such as industrial design, are often required to take one introductory programming subject. Earlier experiences in introducing programming using Java to freshmen have shown that they found programming to be uninteresting and not motivating. Some students struggled to grasp even the basics.

The teaching of programming to students new to it has in general been challenging [10,4]. It is not easy for students to grasp the concepts involved in programming and at the same be proficient at using the syntax of the language of instruction [8]. Like ours, many universities have opted to use Java to teach programming to first year students. The addition of object-oriented concepts and their accompanied syntactical structures does not make it easier to learners. On the contrary, they increase the learning difficulty [1]. To provide students with stronger foundations to cope with Java, we have developed and introduced a new course which incorporated the LEGO MindStorms programmable robots [14; see Figure 1 for sample robots] as the core component of the course. Education researchers have been using the MindStorms in their introductory and advance courses for many years in developed countries including the US, UK, Australia, and Korea (e.g., see [5,6,7,8,13,16,19,20]), and interest is growing in China (see for example [24]).

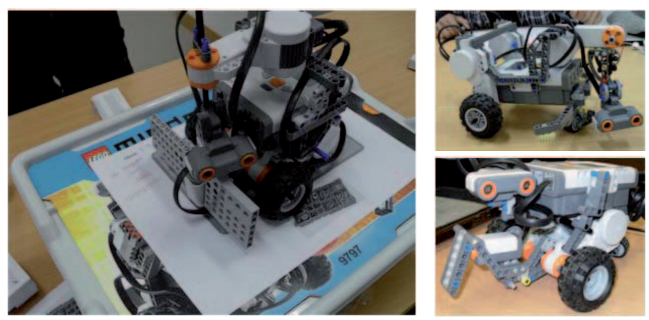

Figure 1. Sample robots built by students using the LEGO MindStorms set.

In this paper we present our experiences of using the MindStorms in an introductory programming course. Three key features distinguish our experiences: (1) whereas the classes in which LEGO MindStorms has been used is relatively small (e.g., 50-80 students in [8,13], the size of our class is large with almost 500 students enrolled in it; (2) the class is taught in English but in a university located in China, where not much is known about the use of the MindStorms in university teaching; and (3) students come from various backgrounds and have different interests. We believe our experiences can be useful to educators who are contemplating using LEGO MindStorms in their classes.

II. Background and Related Work

A. What is LEGO MindStorms?

The LEGO MindStorms is a set composed of a variety of physical pieces (see Figure 2) that can be assembled to produce a variety of robots (see Figure 1). These pieces include beams, gears, blocks, and wheels. It also comes with a set of sensors (touch, light, sound, and ultrasonic) to allow the created robots to interact with its environment. The basic educational set comes with two touch sensors and one light, sound, and ultrasonic sensor. In addition, the set comes with three motors which enable the robots to move around. Attached to each motor is a servo and rotation sensor that measures rotations. This is useful for precise control of synchronized movements of the motors.

Figure 2. The components that come within one LEGO MindStorms set, including 1 NXT micro-computer, 2 touch sensors, 1 ultrasonic sensor, 1 light sensor, 1 sound sensor, 3 interactive servo sensors, and many LEGO pieces.

The main component is a computer brick, named I-Brick (see Figure 3), which contains a micro-processor and can be programmable with different languages. I-Brick, as its centerpiece, connects all other pieces together. It has three output ports for the motors and four input ports for the sensors. I-Brick can communicate with a computer via USB cable or using Bluetooth wireless signals.

Figure 3. The I-Brick connected to the different sensors (http://mindstorms.lego.com/).

The LEGO MindStorms NXT comes with a visual, Drag-and-Drop programming environment, the NXT-G (see Figure 4). NXT-G is designed for people with minimal or no knowledge of programming and is therefore relatively easy to learn how to use. Basically, NXT-G has predefined functions for each of its component (e.g., move for the motors, read inputs from each sensor). The functions are represented as blocks which can be selected and dropped onto the programming board. For example, when the users want to rotate the motors to move forward, they only have to select and drag the motion block from the list and drop it on the board. A combination blocks joined by “sequence beams” will become a program. Wait, Switch, and Loop blocks are used to receive input from the sensors and this information allows users to instruct the robot what actions to take given its environmental conditions.

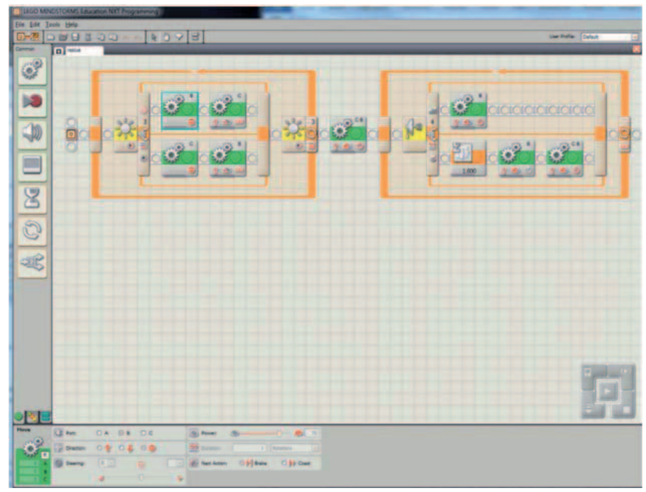

Figure 4. The NXT-G visual programming software used to program the LEGO MindStorms robots.

B. LEGO MindStorms and the teaching of programming concepts

LEGO MindStorms was first introduced in 1998, with the release of the Robotics Invention System kits. Since then many educators have become interested in using the kits to support their teaching, especially of introductory computer science courses. Some of earliest to incorporate the MindStorms sets into a computing course were Wolz [25] and Fagin et al. [7], who used the sets to teach basic programming concepts. Barnes [2] started to use the sets to teach object-oriented concepts, while Klassner [11] used them to teach artificial intelligence. The MindStorms sets are now used as pedagogical tools in many computer science and engineering courses to support the teaching of a variety of subjects from embedded systems [13] to software engineering [16] to robotics [12], in addition to object oriented [2,8,15] and artificial intelligence [11].

Despite educators finding an increasing number of pedagogical applications, the MindStorms remains hugely popular as a tool to support the introduction of programming concepts to students new to it because LEGO MindStorms makes learning of programming concepts '*fun*' and '*interesting*', can often change students' perception and attitude toward programming, and can increasing their motivation to continue further [5,8,15].

Outside of computer and engineering subjects, the LEGO MindStorms sets are also useful to support the instruction of concepts in project management [25] and of skills often required to work in groups [5,8,16].

Given the strong evidence for their use, we are also keen in incorporating the sets into the instruction of our classes, especially at the introductory level. We have attempted this in a large introductory programming courses at an English-based University located in China. In this paper, we describe our approach and students' feedback and impressions on the use of LEGO MindStorms.

III. Using LEGO MindStorms to Introduce Programming Concepts: A Chinese Experience

This section describes our approach in incorporating the LEGO MindStorms sets into a class for first-year university students with minimal exposure to programming. We will also provide students' impressions of the LEGO sets as instructional material.

A. Research methodology

1) Design and procedure

We used a multi-method (quantitative and qualitative) research method and relied on a number of types of data-collection instruments, including activities in lab sessions, questionnaires, interviews, and direct observations of students working with the LEGO sets.

2) Background of students

There were approximately 480 students enrolled in the course. The university is located in China and follows an UK educational system with English being the language of instruction. The students were from all provinces of China and some were overseas students. They were interested in pursuing a bachelor's degree in computer science, electrical and electronics engineering, or industrial design. The students had minimal knowledge and experience with programming—only a handful had some exposure to it during high school.

3) Context and format of the class

We incorporated the LEGO MindStorms sets in a first year introductory programming course which run for 7 consecutive weeks in the second half of the first semester within a 2-semester cycle. One of the authors led the teaching of the class. During the first 4 weeks, students learn basic programming concepts in 2-hour weekly lectures which were complemented with 2-hour weekly labs where students had a chance to put into practice the concepts discussed in lectures. The main concepts covered in lectures were: (1) design and analysis of algorithms, (2) sequential nature of commands, (3) grouping of commands and their reuse, (4) use of conditions, and (4) locating logical errors in a sequence of code.

One of the aims of the course was to provide students with opportunities to explore the dynamics of group, collaborative work, similar to the experiences of [5]. It was therefore decided that students would be working in groups of 3-5 students, with each group dealing with one LEGO set. With 480 students, 119 groups were created by a random selection process.

Students were told of their group assignments in week 4 and each group was given one LEGO set at the same time. The remaining three lectures and labs were dedicated to explaining to the students how to use the different components of the sets and the two challenges that they would need to complete with their LEGO creations in week 7, the last week of the semester. One challenge was a "*rescue mission*", while the other a "*escaping the maze mission*".

The rescue mission was modeled after the rescue task of the RoboCup Junior Australia [22; see Figure 5], a competition for high school students. In this challenge robots would began at the end of a black line and follow the line to its other end. At the end of the line, there would be an area of distinct color representing a chemical spillage with a person trapped in a barrel. To rescue the person, the robot has to push the barrel out of the spillage area.

Figure 5. A team testing their robot on the rescue mission challenge.

The escaping the maze mission was also based on challenges in competitions for high school students. Some researchers have also used this challenge in their teaching—some [9,23] building their maze using black lines placed on the floor and others [20,13] using walls made of wood or thick paper. In the first case, robots would have to follow the black to find the exit, while in the second case they would have to go through the passages between walls (see Figure 6).

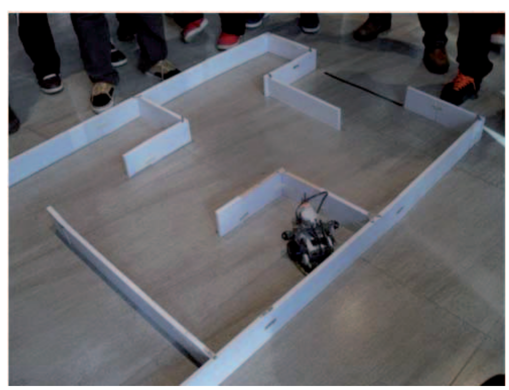

Figure 6. Students observing one robot attempting to scape the maze.

In both challenges, students were given sample models of the challenges to practice, but the final models were not known until the final demonstration, competition day. Their programs needed to be general maze and rescue solvers, and not specific to a known model. For either challenge, each group had two attempts and needed to complete the challenge within 90 seconds.

In the final demonstration, students would have their robot complete one challenge first. They were then given some time to modify their robot and program to complete the other challenge.

After the final demonstrations, students were asked to complete a questionnaire and some of them were selected for a more in-depth interview so that they could elaborate on their answers and also for us to collect further information.

In the next section, we will present the results of the questionnaire and the interviews, together with the notes we collected from observations of students working with the LEGO sets.

B. Results

We collected 364 questionnaire responses. In general, students seemed to have had a good experience with the LEGO sets. Most groups were able to solve the two challenges. The average grade for their group project component was 75%.

In the questionnaire, we asked the students for their feedback and impressions on whether and how the LEGO MindStorms supported their learning process in the course.

1) Overall Effectiveness of LEGO MindStorms

Overall, students perceived the LEGO MindStorms to have been useful in supporting their acquisition of programming fundamentals. Table 1 shows the percentage distribution of answer students gave when asked *how much programming knowledge they had before being exposed and working with the LEGO sets*.

Statement	% responses
I *didn't have any* knowledge of programming.	19.2
I *had little* knowledge.	35.4
I *had some* knowledge.	39.5
I *already had a lot of* knowledge.	5.9
Total	100

Table 1. Students' knowledge level *before* working with LEGO MindStorms

In contrast, Table 2 shows a diametrically opposed set of responses from the students when they were asked the following question: *After working with the LEGO robots in solving the challenges, how much knowledge of computer programming have you gained?*

Statement	% responses
I *didn't gain any* knowledge at all.	1.2
I *gained very little* knowledge.	9.6
I *had some* knowledge.	62.3
I *gained a lot of* knowledge	26.9
Total	100

Table 2. Students' knowledge level *after* working with LEGO MindStorms

2) Did the LEGO MindStorms lead to a positive learning experience of programming concepts?

In the questionnaire, we used *7-point* Likert scale questions, with 1 representing completely *disagree* and 7 completely *agree*, to collect students' subjective opinions on the LEGO sets. The table below summarizes their responses to questions regarding whether and how the LEGO MindStorms provided a positive learning experience.

Questions	Average
I enjoyed working with the LEGO robots.	5.8
The LEGO robots made learning programming *easy*.	5.3
The LEGO robots made learning programming *fun*.	5.6
The LEGO robots made learning programming *interesting*.	5.7

Table 3. Students' perception on whether and how the LEGO MindStorms supported their learning of programming

3) Did the LEGO MindStorms help to acquire specific fundamental programming concepts?

We were also interested in seeing if the LEGO MindStorms and the software that students used to create the programs helped them to understand and acquire some of the fundamental, basic programming concepts, the main aim of the course, so that they could move on to the next year where they would be engaged in learning more advanced concepts.

Questions	Average
Creating the programs for the LEGO Robot has helped me understand about *placing the proper commands at the right places*.	5.6
Creating the programs for the LEGO Robot has helped me understand *how to use conditionals*.	5.6
Creating the programs for the LEGO Robot has helped me understand *how to find errors in my code*.	5.5

Table 4. Students' perception on whether the LEGO MindStorms supported their learning of specific programming concepts

4) Did the students appreciate working in groups?

Being their first year at university, many students had not had experiences working in group projects. We wanted to see if the students appreciated working in a team, especially in the context of learning programming with the LEGO sets. The table below summarizes their responses to these questions.

Questions	Average
It was very enjoyable to work in my group.	5.8
I liked doing the group project.	5.8
The group project was well organized.	5.4
I found that everyone in my group was willing to work hard on the project.	5.3

Table 5. Students' level of appreciation to working in teams.

C. Discussion

The feedback from students about their experiences with the LEGO MindStorms is quite positive. As can be observed from Table 2, 26.9% said that they acquired a lot of knowledge, while 62% stated that they obtained some, but more than just a little, knowledge of programming principles.

In general, the interest of students in getting their hands on the LEGO sets was very high, and so was their willingness to work and "*play*" with them. Students were observed staying up until very late, up to 1-2 AM, in the lab where the sample models were located. They often associate working with the LEGO sets as fun as exemplified by one student's commented: "*It is a fun way to learn programming*"[1]. And even though oftentimes it required persistence and hard work, students seemed to have enjoyed interacting with LEGO sets, as indicated by these two statements by a student: "*By finding mistakes and creating the action of the robot, I got a lot of fun*"; "*We planned how to deal with every problem we meet, and correct the data* [programs] *again and again. In this process, we find knowledge and fun*".

Besides making the process of learning programming *fun*, as Table 3 indicates, students also found that the LEGO sets made the learning programming *easy* and *interesting*. We believe this is because the LEGO sets allowed students to see how the code they wrote works in a concrete manner. For example, students commented that "*I can see easily what the code is doing by looking at how the robots moved. It helps me to learn the commands* [programming] *in a fun manner. It made it not so boring*"; "*Seeing the robots do exactly what I want is interesting*; and "*The robot is very interesting and help me to understand the code*". An interesting element to notice was that even negative feedback was useful to students and this could be extrapolated from the following comment: "*I try the code again and again to correct the answers* [programs]. *The interesting thing is that the robot doesn't always do what you want them to do, so I learn a lot from it*".

[1] The texts are transcribed in verbatim from students' comments. Sometimes there will be words placed within square brackets. They are from the authors and are there to add further clarification to the comments made by the students.

IV. Summary, Conclusions, and Future Work

In this paper, we have described some of our experiences in incorporating the LEGO MindStorms robots sets into a large introductory programming course with more than 480 students at a Chinese university which follows a predominantly UK educational system. The students aim to obtain a degree in either computer science, engineering or industrial design.

Evidence from multiple sources, including grades obtained by students in the group projects, observations made by the instructor, and students' responses on the questionnaires and interviews, converge and indicate a successful integration of the LEGO sets into the course. Whereas students, especially those with little programming background, would be fearful of programming and would have a "just doing enough" attitude to simply pass the class, the students enrolled in our class displayed both appreciation for programming concepts and were looking forward to have greater engagement. Several students wanted to have "*more challenges and more challenging ones*" because by giving "*more challenges to the students,* [and] *not only these two* [as was in the project]*, then it will be more interesting and they will make more efforts on it*".

We believe that the experiences and data presented in this paper will be useful to educators who are planning to integrate LEGO MindStorms into their teaching of programming to novice students who are from different backgrounds and with varied interests, enrolled in a large class, and who attend a university outside of developed countries.

In the future, we want complete the analysis of the students' feedback so that we can incorporate it into the provision of the same course in the following year. For example, some students have mentioned that they would like to have more variety of challenges and to also increase their difficulty level. In addition, we have realized that students have not been able to use some elements of the LEGO sets, such as the gears. We can for example increase the difficulty of the challenges by creating challenges that require the use of gears. However, this choice has to be weighted with other factors. One factor is the time needed to solve the challenges with an increased difficulty level and the time students have available in the semester. In addition, having more variety of challenges makes it more difficult to compare the work of some groups with those of other others groups.

Acknowledgment

LEGO MindStorms is a trademark of the LEGO Group, which does not sponsor, authorize, or endorse any of the third-party cited in this article. None of the authors of this article have any financial relationship with the LEGO Group and its affiliates.

The authors and the Department of Computer Science and Software Engineering would like to acknowledge Xi'an Jiaotong-Liverpool University and all the three departments involved for their support (financial and otherwise) to purchase the LEGO MindStorms kits used in the delivery of the course.

REFERENCES

[1] Astrachan, O., Bruce, K., Koffman, K., Kolling, M. and Reges, S. (2005). Resolved: Objects early has failed. In *Proceedings of SIGCSE'05*, St. Louis, Missouri, USA, pp. 451-452.

[2] Barnes, D. (2002). Teaching introductory Java through LEGO MindStorms models. In *Proceedings of the 33th SIGCSE Technical Symposium on Computer Science Education (SIGCSE '02)*, Covington, Kentucky, pp.147-151.

[3] Begin, J., Lister, R., McNally, M., and Owens, B. (2006). The First Programming Course: Ideas to End the Enrollment Decline. In *ACM Conference on Innovation and Technology in Computer Science Education*, June 26-28, pp. 301-302.

[4] Brusilovsky, P., Calabrese, E., Hvorecky, J., Kouchnirenko, A., and Miller, P. (1997). Mini-languages: A way to learn programming principles. Education and Information Technologies, 2(1), 65-83.

[5] Cliburn, D.C. (2006). A CS0 Course for the Liberal Arts. In Proceedings of the SIGCSE'06, March 1-5, Houston, Texas, pp. 77-81.

[6] Cliburn, D.C. (2006). Experiences with the LEGO MindStorms throughout the Undergraduate Computer Science Curriculum. In Proceedings of the ASEE/IEEE Frontiers in Education Conference, October 18-31, San Diego.

[7] Fagin, B., Merkle, L., Eggers, T. (2001). Teaching computer sciences with robotics using Ada/MindStorms 2.0. In *Proccedings of the 2001 Annual ACM SIGAda Interactional Conference on Ada*, Bloomington, Minnesota, pp.73-78.

[8] Gavan, C. and Anderson, M. (2012). Engaging undergraduate programming students: experiences using lego mindstorms NXT. In *Proceedings of the 13th annual conference on Information technology education (SIGITE '12)*, 139-144.

[9] Jipping, M.J., Calka, C., O'Neil, B., and Padilla, C.R. (2007). Teaching students Java bytecode using LEGO MindStorms robots. In Proceedings of SIGCSE, pp. 170-174.

[10] Kelleher, C. and Pausch, R. (2005). Lowering the Barriers to Programming::A Taxonomy of Programming Environments and Languages For Novice Programmers. *ACM Computer Survey*, 37(2), pp. 83–137.

[11] Klassner, F. (2002). A case study of LEGO MindStorms' suitability for Artificial Intellignece and Robotics courses at the college level. In *Proceedings of the 33th SIGCSE Technical Symposium on Computer Science Education (SIGCSE '02)*, Covington, Kentucky, pp.8-12.

[12] Klassner, F. and Anderson, S.D. (2003) LEGO MindStorms: Not Just for K-12 Anymore. IEEE Robotics & Automation Magazine, June 2003, 12-18.

[13] Kim, S.H. and Jeon, J.W. (2009). Introduction for Freshmen to Embedded Systems Using LEGO Mindstorms. IEEE Transactions on Education, 52(1), 99-108.

[14] LEGO MindStorms (2013). Online: http://mindstorms.lego.com/en-us/Default.aspx. [Last accessed: April 2013].

[15] Lawhead, P.B., Duncan, M.E., Bland, C.G. et al. (2003). A road map for teaching introductory programming using LEGO MindStorms robots. *ACM SIGCSE* Bulletin, Vol.35, Issue 2, pp.191-201.

[16] Lew, M.W., Horton, T.B. and Sherriff, M.S. (2010). Using LEGO MINDSTORMS NXT and LEJOS in an Advanced Software Engineering Course. In Proceedings of the IEEE Conference on Software Engineering Education and Training, pp. 121-128.

[17] McWhorter, W.I. and O'Connor, B.C. (2009). Do LEGO MindStorms Motivate Students in CS1? In Proceedings of the SIGCSE'09, Tennessee, pp. 438-442.

[18] Mead, J., Gray, S., Hamer, J., James, R., Sorva, J., St. Clair, C. and Thomas, L. (2006). A cognitive approach to identifying measurable milestones for programming skill acquisition. SIGCSE Bulletin, 38(4), 182–194.

[19] Sharad, S. (2007). Introducing Embedded Design Concepts to Freshmen and Sophomore Engineering Students with LEGO MINDSTORMS NXT. In Proceedings of the IEEE International Conference of Microelectronic Systems Education.

[20] Simon (2010). Using a primary-school challenge in a third-year IT course. In *Proceedings of the 12th Australasian Computing Education Conference (ACE '10)*, Brisbane, Australia, pp.147-153.

[21] Qi, C. (1988). Computer education in secondary schools in the People's Republic of China. Journal of Research in Science Teaching, 25(6), 493-500.

[22] RoboCup Junior Australia (2013). Online: http://www.robocupjunior.org.au/ [Last accessed: April 2013].

[23] Sklar, E., Parsons, S., and Stone, P. (2004). Using RoboCup in university-level computer science education. ACM Journal on Educational Resources in Computing, 4(2), 1-21.

[24] Yu, X. (2012). Using LEGO Mindstorms in the Undergraduate Curriculum of IT. In *Proceedings of the 2012 International Symposium on Information Technology in Medicine and Education (ITME '12)*, 3-5 August, pp. 270-273.

[25] Wolz, U. (2001). Teaching design and project management with LEGO RCX Robots. In *Proceedings of the 32th SIGCSE Technical Symposium on Computer Science Education (SIGCE '01)*, Charlotte, NC, pp.95-99.