World Transactions on Engineering and Technology Education
Vol.3, No.1, 2004

Smart systems used as an educational aid in mechanical engineering

Sabu John, Dean Reeves, Robert Evans & Ben Bundy

Royal Melbourne Institute of Technology University
Melbourne, Australia

ABSTRACT: The low cost accessibility of so-called *smart* systems, such as the LEGO Mindstorms™ kit, now allows undergraduate engineering students to gain a thorough understanding of not only mechanical devices, but mechatronic devices as well. The LEGO Mindstorms™ kits allow for the construction of mechanical and mechatronic entities of varying complexity from very easy to highly complex. Building a mechatronic device calls on the student to use the knowledge from various disciplines such as mechanical, electrical, electronics, software and control engineering. A series of LEGO Mindstorms™ lessons have been created, culminating in a series of project challenges, which are targeted at the student relatively new to the engineering degree. The article gives a brief insight into the learning process of students as they use this kit to construct these devices to varying degrees of complexity.

INTRODUCTION

Smart systems in this article refer to systems that include hardware, computing and signal processing, sensors and actuators. One such system recently introduced is the LEGO Mindstorms™ system. LEGO not only produces an intricate array of highly specialised mechanical, electrical and computational products, but also specific kits designed exclusively for use in the educational environment. LEGO can provide for a learning experience far beyond that possible through an environment of pure theory, and at a cost far lower than was ever the case previously. Highly complex mechatronic/robotic devices can now be made by a single student or group of students in conjunction with the engineering theory gained through the educational institution. On completion of a project, the components can be disassembled and readied for use by other groups, providing a factor of reusability not available previously, further adding to the cost effectiveness of the system.

LEGO Mindstorms™ can draw on the application of a variety of engineering skills. These include mechanical engineering, electrical/electronic engineering, robotics, mechatronics, computer programming and hands on construction. For this reason, the lessons will not only be of use to mechanical engineering students, but also those of other disciplines. Therefore, it also aids in interdisciplinary understanding and the application of engineering specialities.

The objective of this article is to show how educational lessons can be developed as projects for tertiary students in the initial stages of their mechanical engineering studies. The LEGO Mindstorms™ system will be used for the practical application of technical challenges, while the design of the lessons will, to a certain extent, be based on Benjamin S. Bloom's *Taxonomy of Educational Objectives* [1]. Bloom's taxonomy identifies six different levels of learning within the cognitive domain. The levels are as follows:

- Knowledge;
- Comprehension;
- Application;
- Analysis;
- Synthesis;
- Evaluation.

This project aims to relate at least the first four of Bloom's taxonomies to the development of a LEGO educational system for students of engineering. In doing so, the aim is to help inspire students who are beginning their studies in mechanical engineering and achieve a level and depth of understanding not previously experienced in the initial stages of a mechanical engineering degree.

WHY LEGO?

The supremacy of LEGO resides in its reusability and near infinite combination of possible outcomes, given a certain kit. In the educational environment, its reusability allows for a high level of cost effectiveness because of its high durability and low price.

The ready-to-use components allow for a quick building and experimentation process. When asked to solve an engineering problem, no two students are likely to come up with exactly the same solution, due to the extensive number of combinations available to solve a problem. This gives the builders unparalleled opportunity to explore not only their own design solutions, but those of others around them. These design solutions relate not only to the mechanical aspect of a certain mechatronic device, but also the programming and electronic characteristics.

LEGO has already been adopted by a number of universities in the USA for use in their engineering programmes. Indeed, many universities in the USA already have LEGO Mindstorms™ subjects as part of their curricula. Those universities include the Massachusetts Institute of Technology (MIT), Boston University, Stanford University and Tufts University, to name a few.

THE LEGO MINDSTORMS™ HARDWARE

The core components in a typical Mindstorms educational kit are as follows: programmable brick; infrared control tower; touch sensors; light sensors; electric motors; gears and pulleys; wheels and axles; and building bricks

The software used to program the robots is sold separately and, as stated before, is known as *Robolab*. Once the software and kit has been purchased, one can go about building a fully functioning robot.

Most of the above components are self explanatory, except for the programmable brick, which needs some explaining. As can be seen in Figure 1, the brick consists of three outputs and three inputs. Attached to the inputs can be items such as the light sensor or touch sensor. The outputs would then generally control one of a number of electric motors. The program, as written using the *Robolab* software, is sent to the programmable brick via an infrared tower.

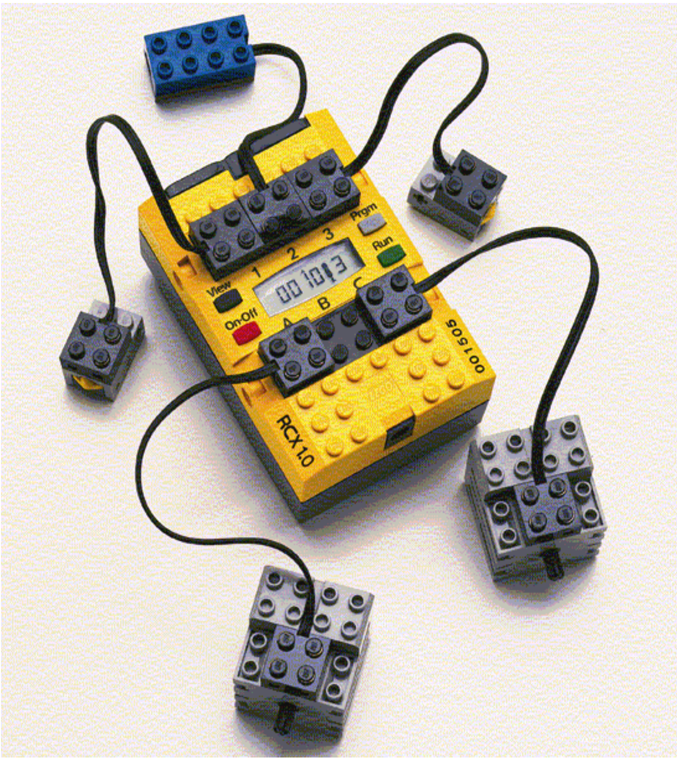

Figure 1: LEGO RCX Programmable brick [2].

The *Robolab* software contains a number of modules, namely: Programmer and Investigator. The Programmer module has two difficulty levels: Pilot and Inventor. Pilot is for basic programming while Inventor is for complex tasks. This report will focus on Inventor as its primary programming language, as the Pilot level is seen to be too basic for the tertiary environment. The Investigator module is based on *Labview* software, which allows for an analysis of certain aspects of the robot's performance.

The Inventor programming language is icon-based. This allows for rapid learning for students participating in robot building. Although other languages can be used to program the RCX brick, such as NQC (Not Quite C) and Java, it is not a primary objective of Mindstorm robot building to delve into complex programming languages. By using the *Robolab* icon-based software, a student maintains a high level of interest in achieving a specific goal and not becoming disillusioned with pure programming. This is not to say advanced engineering students will not want to investigate higher level languages, which is certainly an option.

As shown in Figure 2, the programmer places icons according to a certain objective. For example, turn on motor connected to output A. Once the program is complete, it is sent to the RCX brick via the infrared tower. This software even has the ability to use image recognition in conjunction with a mini camera attached to the robot.

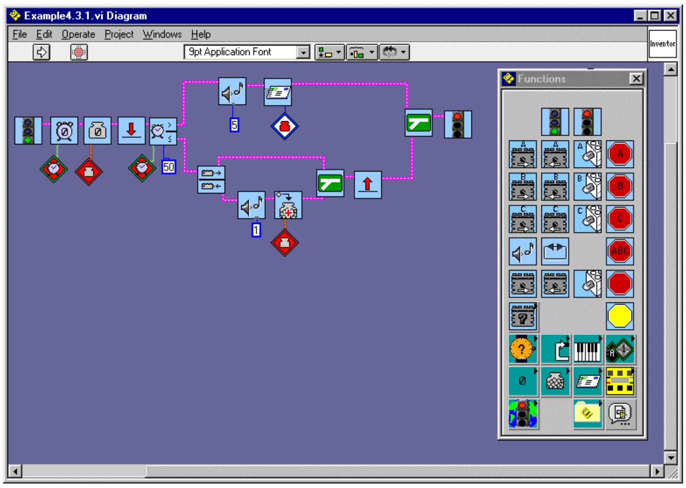

Figure 2: *Robolab* Inventor GUI [2].

Finally, any robot built can have assembly instructions created, allowing for engineering communication to also play a role in the learning process. The software used for this purpose is LEGO CAD. There are other third party software applications available for this purpose.

BLOOM'S TAXONOMY AND USAGE

In 1956, Benjamin Bloom headed a group of educational psychologists who developed a classification of levels of intellectual behaviour considered important in learning. Bloom found that over 95% of the test questions that students encountered required them to think only at the lowest possible level, such as the recall of information. Bloom identified six levels within the cognitive domain, from the simple recall or recognition of facts as the lowest level, through increasingly more complex and abstract mental levels, to the highest order, which is classified as *evaluation* (see Figure 3) [1].

Earlier attempts to use Bloom's taxonomy and smart systems, such as the LEGO Mindstorms™ kit, has been reported by John, Netherwood, Fernandez and Sudarmo [4].

The Mindstorm lessons and projects have been structured to be aligned with the educational model of the proven educational taxonomy of Benjamin Bloom. In doing so, the engineering student will gain the basic knowledge needed to construct and program devices, right through to building working models of their own, either individually or as a team. By requiring that a student build a device of their own design, from start to finish, including programming and construction, it ensures that they are taking their learning behaviour out of that region identified by Bloom to which 95% of the test questions encountered by students occur, in the region of pure knowledge and into far deeper cognitive regions.

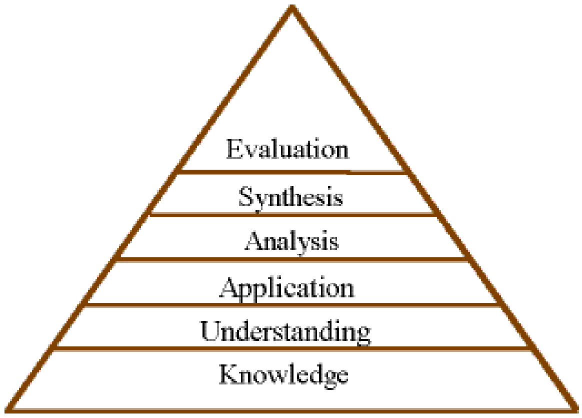

Figure 3: Bloom's hierarchy of the cognitive domain [3].

Although it is beyond the scope of this project to follow every aspect of Blooms taxonomy in the construction of Mindstorm robots, it will be followed to the extent that the underlying philosophy is met. The taxonomy has been linked in the following manner to the LEGO Mindstorms™ kit described below.

Knowledge

Introductory lessons, as shown in the lesson structure, give students the basic knowledge and practical usage of the Mindstorm kits in so far as building basic mechanical and electrical devices. As shown by Bloom, the student need only follow the instructions, thereby gaining knowledge of components available in the LEGO Mindstorms™ kits and how to assemble them. However, this knowledge is vital for success in the later construction modules. The programming lesson outlines how one should go about programming the RCX computer in the *Robolab* software format.

Comprehension or Understanding

During the basic lessons, small challenges have been created to build another device based on one that they have previously constructed. If the student has understood the concepts they will be able to build the mechanism.

Analysis and Synthesis

After the introductory lessons have been completed, the student will move on to harder construction projects (also seen below). Each project will be unique and increase in difficulty as they go from project to project. With the knowledge gained in the introductory lessons, the student or student group should be able to achieve a design solution that will incorporate building and programming the device. On completion of the last device, the student should be very well versed in the construction of mechatronic devices using the Mindstorm system. By this stage, the student should be able to progress even further by inventing devices autonomously.

LESSONS

The lessons for linear/rotary, 2-dimensional, 3-dimensional, eccentric, grabbing and locomotion, are pure construction. So long as the student has a full set of the LEGO Mindstorms™ kit at their disposal, assembling the devices should be non-problematic. These initial lessons are a vital process if a student has never worked with LEGO before, or has limited mechanical engineering experience. Many people believe that because it is LEGO, it will be easy to build working devices; however, this is far from reality, as described in Agullo *et al* [5].

The programming requires a full working version of *Robolab* software. This software is very powerful and built on top of the well-known scientific software known as *Labview*.

BLOOM'S TAXONOMIES INTERACTION WITH THE LEGO MINDSTORMS™ CONSTRUCT

To show how Bloom's taxonomy has interacted with the LEGO constructs, the first five of Bloom's taxonomies – including knowledge, comprehension, application, analysis and synthesis – will be expanded upon in relation to the learning package. The *evaluation* region could be expanded upon in a group learning environment where the aims can be met. However, it has not been able to be tested in this article. It must be remembered that although there are six areas in Bloom's taxonomy, a system like building a mechatronic device will see a crossover in the taxonomies and there is not always a clear delineation between each area.

Knowledge

In order to build any kind of mechanism with the Mindstorm kits, a student must know what components are available, what those parts do and how to best assemble them. For example, a student may not have known how gearing ratios will influence the performance of their mechanism or which gears are available for a particular application. However, this knowledge is gained after the introductory lessons, for example: linear or grabbing motion construct.

Comprehension

Following the building instructions given and watching the finished device in operation gives the student the ability to visualise how certain parts interact with each other and how changing these parts affects their device. An example of this involves the sensors that are integrated with locomotion devices.

Application

Having completed the introductory lessons, the student moves on to the first project challenge. This is the first time they are expected to think of an individual design solution based on the challenge topic and some background information. One example of this is the mobile book climber.

Analysis and Synthesis

By the time that the prospective student reaches the second design challenge, he/she will be exploring all of their mechatronic and programming abilities. Here, the student is expected to analyse what is needed of a device that relies heavily on mechanical design, programming, electrical systems and sensors. The completion of the project shows an excellent ability within the multidisciplinary understanding needed of a mechatronic device.

The last LEGO Mindstorms™ challenge really fuses all of the student's knowledge into a quite complex mechatronic device. As an example, the walking biped (see Figure 4) requires some very clever mechanisms, sensors and programming to be incorporated for the biped to be completed successfully.

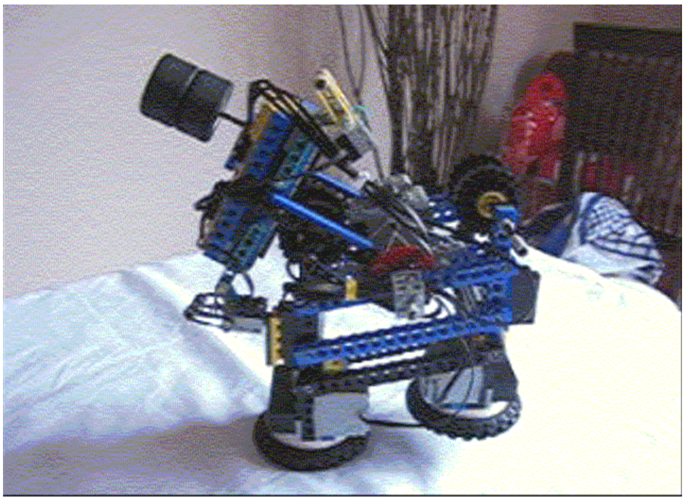

Figure 4: A walking biped machine.

CONCLUSION

In review, a smart system, such as the LEGO Mindstorms™ system, can be, and has proven to be, useful here and in other tertiary institutions as a learning aid for mechanical engineering, especially in mechatronics. Its target group is most likely new engineering students, with its value diminishing in the more advanced years. With an educational plan as created here, in accordance with Bloom's structure, the student should achieve outcomes in most of the six taxonomies identified by Bloom.

REFERENCES

1. Bloom, B.S. (Ed.), *Taxonomy of Educational Objectives: the Classification of Educational Goals: Handbook I, Cognitive Domain*. New York: Longmans (1956).
2. Tufts University, LEGO Mindstorms Web site, http://www.ceeo.tufts.edu/robolabatceeo
3. Bloom's Taxonomy, http://www.officeport.com/edu/blooms.htm
4. John, S., Netherwood, G., Fernandez, G. & Sudarmo, Learning taxonomy analyses of student-based activities using the LEGO Mindstorms system. *Proc. 13th Australasian Conf. on Engng. Educ*., Canberra, Australia, 159-164 (2002).
5. Agullo, M., Carlson, D., Clague, K., Ferrari, G., Ferrari, M., Yabuki, H. and Hempel, R., *LEGO Mindstorms Masterpieces*. Rockland: Syngress Publishing (2003).