INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED13
19-22 AUGUST 2013, SUNGKYUNKWAN UNIVERSITY, SEOUL, KOREA

THE DEVELOPMENT OF A LEGO MINDSTORMS-BASED CURRICULUM FOR DESIGN AND ERGONOMICS STUDENTS

David W. GARRETT, Peter J. UNDERWOOD, Gyuchan Thomas JUN
Loughborough University, United Kingdom

ABSTRACT

Design students' understanding of design processes and their ability to continually improve on them is a fundamental concern in design education. This paper discusses a curriculum development project at Loughborough Design School, investigating the use of LEGO Mindstorms as the basis for a system design learning activity. A range of studies have demonstrated the value of Mindstorms in higher education applications. However, these have typically focused on undergraduate engineering courses and emphasise the development of technical skills. Our aim was to create a learning activity for students from a range of design programmes, focusing on their understanding of design processes. We developed a team design learning activity for undergraduate design and ergonomics students, and conducted a pilot study to assess the feasibility and value of this approach to student learning. This has shown the potential usefulness of Mindstorms problem-based learning activities in improving students' understanding of the design process.

Keywords: design education, design learning, design process, Lego Mindstorms, ergonomics

Contact:
Dr. Thomas Jun
Loughborough University
Loughborough Design School
Loughborough
LE113TU
United Kingdom
G.Jun@lboro.ac.uk

1 INTRODUCTION

The system design process is a fundamental consideration in design education. There is a growing awareness within industry that improvements in processes are vital to business success (Clarkson & Eckert, 2005). Therefore, it is of central importance that design and engineering students can reflect on their design practices and continually improve on them.

Loughborough Design School provides four different undergraduate design-based courses: industrial design and technology, product design and technology, design ergonomics and ergonomics. The ergonomics course brings together elements of biology, psychology and design. However, it was observed that ergonomics students have a knowledge gap in applying ergonomics approaches in the context of overall system design processes. To address this gap, the authors of this study developed a LEGO Mindstorms-based system design curriculum, initially aimed at ergonomics students. This initiative was sponsored by a University Teaching Innovation Award, funding two pedagogic research assistant roles for a short period.

The initial inspiration for this project came from two learning activities developed at the University of Cambridge, involving undergraduate and postgraduate engineering students respectively. In wider higher education studies, LEGO Mindstorms-based education has been found to offer a valuable learning basis for design task management, problem solving, student engagement, independent learning and team project skills. A literature review has revealed a variety of applications of LEGO Mindstorms in higher education, aimed at different learning objectives. Table 1 summarises the findings from the review of the two courses at the University of Cambridge, and thirteen published articles (Fukui & Sato, 2011; Gómez-De-Gabriel et al., 2011; Ishii et al., 2010; Jaksic & Spencer, 2008; Kim & Jeon, 2009; Lai-Yuen, 2008; Langer & Strothotte, 2007; Lew et al., 2010; Min et al., 2009; Pears & Daniels, 2010; Pomalaza-Ráez & Groff, 2003; Schubert et al., 2009; Williams, 2003).

Table 1. Uses of LEGO Mindstorms in higher education

LEGO Mindstorms in Higher Education	**Description**
Countries	China, Finland, Germany, Japan, South Korea, Sweden, Spain, UK and USA
Year group	First year undergraduates, senior undergraduates and postgraduates
Courses	General engineering; systems and industrial engineering; software engineering; industrial design
Class size	From 6 up to 340 students; one case includes inter-continental collaborative class between two universities
Group size	2-6 students per team
Learning objectives	• Design process-focused Problem solving; Creativity; Communication, Collaboration • Technical aspect-focused Software development; Bluetooth communication; Web-based programming; Embedded systems
LEGO project types	• Open-ended: to provide an example to show the required level of system complexity to be developed • Goal-driven: to provide target performance and functions which the final system should achieve, e.g. domino alignment robot, delivery robot, line-following robot, racing robot, two robots communicating each other, etc • Instruction-based: to provide building instructions to follow

LEGO project number	• Single project - One final design - First design and redesign (iterative) • Multiple projects: two to five projects with different complexity (simple, intermediate and complex)
LEGO project duration	• Weekly lectures and laboratory sessions in parallel (throughout one semester) • Intensive workshop session (short period, e.g. one week)
Control software	LEGO NXT s/w, LeJOS (Java for LEGO Mindstorms), LABVIEW, MATLAB, Octave and low level network programming
Assessment	Demonstration, in-class competition, verbal presentation and written documentation

Given the particular aims of our project, and the quite diverse possibilities for running LEGO Mindstorms-based teaching sessions, it was necessary to conduct a study to investigate the use of this system, relevant to design processes in our own context. The project focus was the development of a LEGO Mindstorms-based system design curriculum, which will help equip ergonomics students to apply human factors approaches in the context of overall system development processes. This paper discusses our LEGO Mindstorms-based curriculum development process, including planning, feasibility testing, training material development and piloting.

2 METHOD

2.1 Initial planning

Our aim was to devise a suitable learning activity to teach some general characteristics of design processes. The first task involved determining which characteristics of design processes we wanted to teach. We identified some specific features of interest including design uncertainties, interdependencies, trade-offs and the iterative nature of design processes.

The learning activity needed to take account of the general nature of design teaching in the department and the relevant skill level of potential participants. First or second year undergraduate design students from a range of programmes were considered to be suitable participants and were expected to have little or no previous experience of LEGO Mindstorms. Our intention was to produce a transferable learning activity, initially forming a component of an ergonomics module and relating only broadly to its content in terms of general design process learning. The development of programming or other technical skills was not a required learning outcome. Moreover, as a problem-based learning activity, our intention was to provide the minimum necessary instruction, thereby allowing participants to develop their own understanding of the design task as far as possible. We needed only to provide sufficient support for participants to begin the task efficiently.

The second task, given the target student group and intended learning outcomes, was deciding the type of project we wanted students to carry out. The project examples from Cambridge and from the literature, were oriented towards technical functions, e.g. robots for delivery, line following, domino alignment, etc. Partly to enhance the ergonomic dimension to the project to help ergonomics students engage in the learning activity, the idea of a line-following electronic wheel chair for teddy bears was chosen as a project idea.

2.2 Feasibility testing

Two LEGO Mindstorms NXT Education Base Sets were acquired for development of the learning activity, given that the subsequent pilot study would involve two student teams. Three short feasibility testing sessions among the authors were organised. Preparatory work involved testing some basic vehicle chassis designs, capable of being produced and performing a line-following task within two two-hour laboratory sessions. Figure 1 shows one of these vehicle designs which was to provide swift and secure transportation for a teddy bear.

Figure 1. One of the vehicle designs produced during feasibility testing

The feasibility study led to a short design brief for the task, with a fairly open specification for an automated line-following vehicle. The task entailed an iterative process of vehicle design, construction and testing to produce a final vehicle capable of completing a time trial around a simple oval track. To further enhance the ergonomic dimension to the challenge, vehicles were to convey two different passengers around the track, switching these quickly at the midpoint of the time trial. The task as designed was considered to combine accessibility and relevance to students across the design programmes, with sufficient complexity to necessitate an iterative and cooperative team design process.

2.3 Piloting

A pilot study was planned to evaluate the practicality of the learning activity and its contribution to students' learning. Eight second year design undergraduate student volunteers were recruited and the two teams were formed with an almost equal mix of students from each of the four design programmes. As expected, initial responses indicated most had no experience of Mindstorms, although most had at least some experience with LEGO.

In the piloting sessions, student reflective discussions were planned for different stages and the outcomes of these were intended also to contribute to the learning activity evaluation. In addition, participant feedback was to be obtained at the end of the learning activity using structured feedback sheets, based partly on standard module feedback questionnaires used locally. All elements were required to fit within the two two-hour sessions, allowing as much time as possible for the participants to attempt the design task. The final pilot session plan is summarised in Table 2.

Table 2: Design for pilot sessions

1st session (week 1)	2nd session (week 2)
Introduction (10 minutes)	Group work (85 minutes)
Group discussion (10 minutes)	Time-trial competition (10 minutes)
Technical introduction (10 minutes)	Group reflection (15 minutes)
Group work (90 minutes)	Final evaluation (10 minutes)

The first 10 minute presentation comprised an overview of the learning objectives, a discussion of a generic design process and design project brief, as well as a short introduction to the LEGO Mindstorms system. Following this was a short student team discussion of the design process in relation to their own previous team designing experiences. This discussion was intended partly as an opportunity for team introductions, but also as a chance for teams to explore and reinforce some of the key learning points by creating flip chart and post-it note summaries. This was followed by two short technical presentations, introducing some of the basic elements of LEGO mechanical design and control design using the standard NXT-G software, actuators and sensors. Handouts were also produced in support of these activities and to outline the full task rules and requirements. It was made clear that these technical aspects of the task did not represent key learning goals.

Four notional design roles were specified for the four students in each team: *control engineer, human factors engineer*, *mechanical engineer*, and a *project coordinator*. These roles encouraged team members to take somewhat distinct areas of responsibility and focused perspectives on the design problem but with flexibility for cooperative design development throughout. Simple summary role descriptions were provided to students during the introductory presentation, as follows:

- The *control engineer* is responsible for creating a program to control the vehicle.
- The *mechanical engineer* is responsible for designing the chassis.
- The *human factors engineer* is responsible for designing a suitable way to carry passengers.
- The *project coordinator* is responsible for keeping track of the design process and ensuring it runs smoothly.
- Remember that you are all working as a team to produce a whole working design.

The coordinator role involved reflective observation of their team process, intended to encourage more effective reflection by the whole team throughout the design process. This role was supported by a structured observation template, reflecting the key features and broad stages of the design process. This single page template is reproduced in Figure 2.

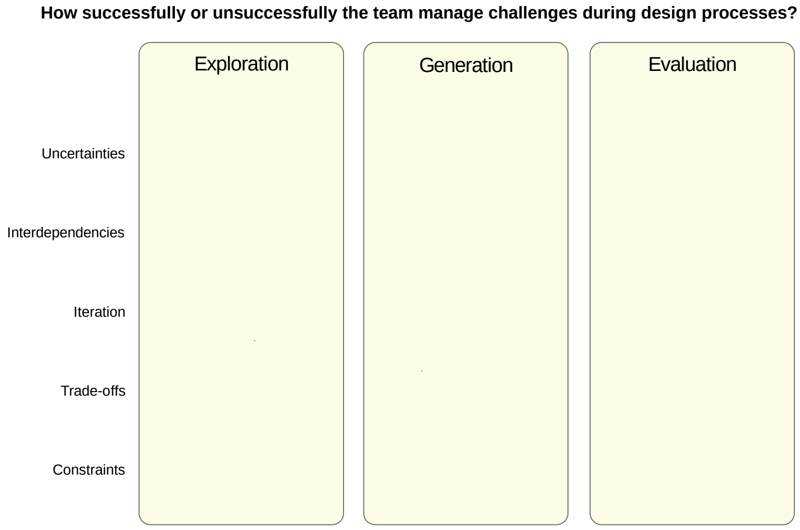

Figure 2. The observation template for the coordinator role

Directly after the introductory presentations, the selection of team roles was to be negotiated by the students themselves as work on the design challenge commenced. Work on the design task was scheduled to fill most of the two sessions and was to be followed by a short time trial competition. After this, extended group reflection on the task as a whole would include both the design process and participants' experiences of team working and of the design challenge. Finally, student feedback sheets were to be completed. These were designed to capture student perceptions of the learning experience, as well as an indication of their actual level of understanding following the activity.

3 RESULTS

3.1 Pilot session observations

Following the initial introductory presentation, the first group discussions indicated that students remained unclear about key features of the design process and they struggled to articulate links to their own previous team designing experiences. Students seemed attentive during the short technical presentations, after which team members selected their roles readily and began the task directly.

From early on in the session both similarities and quite marked differences were seen in the approaches taken by the two teams. For example, while the control engineers in both cases started work apart from others in their teams, all members of Team A collaborated more extensively on various other aspects of the task, while those in Team B remained more conspicuously within their chosen roles. As the first session unfolded, Team A drew ahead in all aspects of the task, while Team

B progressed more slowly and with redundant team members for significant periods of time. While this was possibly compounded in part by equipment issues, Team B's approach ultimately proved costly in terms of a weak mechanical design and fundamental control issues that remained unresolved at the end of the task. Team A had sufficient time to explore different vehicle designs but, having resolved most issues to create an early working prototype, their subsequent experimentation with different mechanical features and related control changes led ultimately to a slightly less successful final design. The final vehicles produced by the two teams are shown in Figure 3.

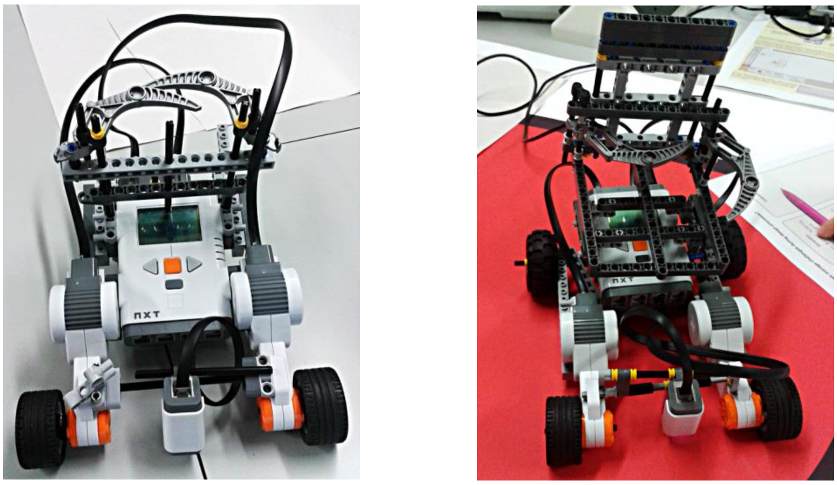

Figure 3. Final student vehicle designs

Both sessions saw a full turnout of student volunteers, and both teams seemed to remain largely focused on the task throughout, showing a clear interest in gaining from the learning experience. This remained the case for the most part, irrespective of their success in resolving particular design challenges and despite some tiredness and a lack of energy among most of the students in the second session following a major coursework deadline earlier that day. As only one team had completed a fully functional vehicle by the end of the second session, the planned final time trial was not held and instead the final discussion and feedback components were held directly.

3.2 Student feedback

The feedback sheets were completed diligently by all the students and proved a useful basis for evaluating the overall success of the session. A number of questions required a graded response, of *strongly disagree*, *disagree*, *neutral*, *agree* or *strongly agree*. These responses are assigned scores from 1 to 5 respectively. There was general agreement that the learning activity overall was well organised and that it was clearly explained, with an average score of 4.4 in both respects. Students felt most strongly that they were encouraged to participate in the task, with an average agreement of 4.8. Support, through feedback given during the sessions, was also highly rated across all roles, with an average score of 4.3. However, there was a mixed response regarding the suitability of the introduction and handout materials in supporting the different roles, with an average score below 4.0 (despite prompting, the handouts were seen to receive limited attention throughout). Nonetheless, students felt their confidence in tackling future design tasks had improved, with an average agreement of 4.3. They also felt the relevance of the task to their wider design studies was clear, with an average score of 4.4. They unanimously agreed that this learning experience would be valuable to their peers, in their respective design programmes.

In terms of the key design process learning points, for each of the core features of the design process students almost invariably agreed that their understanding had improved, with only two responses of "neutral" and an average score across all items of 4.0. However, their attempts to articulate this understanding in short free responses on each aspect of the design process showed there had been mixed success in understanding these features.

4 DISCUSSION

Our observations of the design processes highlighted where some of the key learning activity challenges are. These relate particularly to the control and mechanical aspects, which contain the greater technical challenges and the largest number of interdependent elements that must be appropriately implemented for vehicles to function well. As such, these aspects of the task tend to take the focus. However, other aspects of the task also met with mixed success. The coordinator role was successful in generating various student observations of the process and evidenced some wider thinking about the nature and success of the process. However, this role may benefit from changes to the support given and appeared to be performed unevenly, i.e. making partial use of the observation template and requiring prompting at times. More structured integration between this and other team reflective activities might also prove valuable to overall team design process learning.

Compared with approaches found in the LEGO Mindstorms-based educational literature reviewed here, the approach taken in the present study appears distinctive in a number of respects. Other approaches have tended to involve engineering programmes and were often aimed at teaching technical skills, such as programming, rather than a more generic understanding of design processes or skills in collaborative designing. There appear to be limited precedents for the use of Mindstorms in product design education. Langer and Strothotte (2007) is one instance of this. However, in their interaction design focus they too were particularly interested in the roles of software and hardware in designing and less in the design process itself. They also conform to the general pattern of semester-long programmes, conducting a course with an extended period of teaching and design development. This comprised a series of smaller projects, creating learning stages of increasing sophistication. Students spent 4-6 hours on each stage, progressively developing their understanding of the Mindstorms system.

While many design tasks were relatively complex, in all of the reviewed examples the longer timescales allowed more time to come to terms with the design process and the design challenges and to resolve issues as they arose. Jaksic and Spencer (2008), for example, indicate the possibility of control complexities beyond the software interface or program logic; in their case the effectiveness of light sensors under differing light conditions. Courses also often involved greater integration of the design task within structured software training, particularly where the intention was to teach programming skills. The Cambridge undergraduate task, though not preceded by specific training, was nonetheless intended to integrate with the wider engineering programme and it also allowed a slightly longer development period for the systems involved. Their postgraduate task, with a core emphasis on the design process, is perhaps the instance with teaching aims most comparable to our own. However, although this involved two practical sessions of similar duration to our own, differences included a narrower focus on controlling a pre-designed robot and relevant systems design teaching over a period of several weeks between the two sessions.

Problem-based learning opportunities, offering substantially self-directed, open-ended and creative design challenges, can in general encourage student engagement and motivation. Jaksic and Spencer (2008) similarly comment on an intrinsic motivational property of mechatronics tasks; while Pomalaza-Ráez and Groff (2003) discuss the value of their robotics programme to the induction and retention of undergraduate engineering students. This appeared to be reflected in our own case, for example, in the ease of recruiting volunteers and in the full turnout and consistent level of engagement throughout the pilot study sessions. Moreover, the final feedback responses we obtained indicated that not completing the task entirely successfully did not necessarily reduce the value of the learning experience or result in a less favourable response from the students overall.

5 CONCLUSIONS AND FUTURE WORK

Overall the learning activity was well received and a consistently high level of engagement and interest was shown in the design task. The students considered this unusual team design opportunity to be a valuable and enjoyable learning experience, during which they had improved their understanding of the design process. It was unanimously recommended as an activity for their peers across the various design programmes.

Nonetheless, potential areas for improvement have been identified. Future work should investigate how a fuller curriculum design might allow more successful engagement with technical aspects of the task and how this might integrate more fully with core aspects of design learning at Loughborough Design School. Elements of task redesign might include exploring the use of LabVIEW software, used in a number of the reviewed studies, and also used locally for different tasks. Also consistent with wider learning aims, would be the development of systems modelling skills as a component of Mindstorms activities; a possibility demonstrated by Ishii et al. (2010). With additional time, the testing of further configurations of vehicle, sensor and track designs may also prove useful in refining the task and some aspects of the support. Changes should avoid adding inappropriate technical complexity to the design task, even if its duration is extended.

In terms of the whole learning design, a longer course with a more stepwise progression from introductory to more sophisticated design tasks might also prove valuable. In our case this should reflect the balanced involvement of coordinator, mechanical and human factors roles, as well as control designing. For relevance across design programmes, it is important to maintain our emphasis on a transferable teaching design with a focus on generic team design process learning. In this there is scope for attention to the design of reflective learning activities, beyond the scope of the present short project. While complexity of the learning activity and curriculum development task has been kept to a manageable level in this study, the explicit inclusion of further design considerations characteristic of real world designing, notably core concerns in designing for sustainability, would become more viable in an extended approach.

ACKNOWLEDGMENTS

The authors would like to thank Professor John Clarkson, Dr Andrew Gee and Dr Alexander Komashie at the University of Cambridge for kindly providing information on their courses. We also would like to thank Dr Tom Page and Ms Sarah Bamforth at Loughborough University for their invaluable advice. Most of all, we are grateful to all the students who participated in the piloting. This work is supported by a Teaching Innovation Award by the Teaching Centre at Loughborough University.

REFERENCES

Clarkson, P. J., & Eckert, C. (2005). Design Process Improvement: A Review of Current Practice. London: Springer.

Fukui, R., & Sato, T. (2011). Educational activities with a focus on robot strategies - through the development of LEGO manipulation robots -. *Journal of Robotics and Mechatronics* 23, 759-767.

Gómez-De-Gabriel, J. M., Mandow, A., Fernández-Lozano, J., & García-Cerezo, A. J. (2011). Using LEGO NXT mobile robots with Lab VIEW for undergraduate courses on mechatronics. *IEEE Transactions on Education* 54, 41-47.

Ishii, N., Suzuki, Y., Fujiyoshi, H., & Fujii, T. (2010). Fostering UML modeling skills and social skills through programming education. *Software Engineering Education Conference, Proceedings*, 25-32.

Jaksic, N., & Spencer, D. (2008). A multidisciplinary laboratory course: Robotic design and programming with mindstorms. *ASEE Annual Conference and Exposition, Conference Proceedings*.

Kim, S. H., & Jeon, J. W. (2009). Introduction for freshmen to embedded systems using LEGO mindstorms. *IEEE Transactions on Education* 52, 99-108.

Lai-Yuen, S. (2008). Using lego to teach and learn micromanufacturing and industrial automation. *ASEE Annual Conference and Exposition, Conference Proceedings*.

Langer, C., & Strothotte, C. (2007). The benefits of integrating LEGO mindstorms into design education. Course "media systems". *DS 43: Proceedings of E and PDE 2007, the 9th International Conference on Engineering and Product Design Education*, 337-342.

Lew, M. W., Horton, T. B., & Sherriff, M. S. (2010). Using LEGO Mindstorms NXT and LeJOS in an advanced software engineering course. *Software Engineering Education Conference, Proceedings*, 121-128.

Min, S., Seo, S., Kim, J., Kwon, K. H., Hwang, S., & Jeon, J. W. (2009). A creative engineering design course for freshman using LEGO robots. *IEEE International Symposium on Industrial Electronics*, 960-965.

Pears, A., & Daniels, M. (2010). Developing global teamwork skills: The runestone project. *2010 IEEE Education Engineering Conference, EDUCON 2010*, 1051-1056.

Pomalaza-Ráez, C., & Groff, B. H. (2003). Retention 101: Where robots go...students follow. *Journal of Engineering Education* 92, 85-90.

Schubert, T., Jacobitz, F., & Kim, E. (2009). The engineering design process: An assessment of student perceptions and learning at the freshmen level. *ASEE Annual Conference and Exposition, Conference Proceedings*.

Williams, A. B. (2003). The qualitative impact of using LEGO MINDSTORMS robots to teach computer engineering. *IEEE Transactions on Education* 46, 206.