Development of an Undergraduate Multidisciplinary Engineering Project

Dr David Ryan Smith, *david.smith@brunel.ac.uk*
School of Engineering and Design, Brunel University, Uxbridge, Middlesex, UB8 3PH, UK

Dr Jo Cole, *joanne.cole@brunel.ac.uk*
School of Engineering and Design, Brunel University, Uxbridge, Middlesex, UB8 3PH, UK

Abstract

During their time at university it is necessary for undergraduate engineering students to develop not just technical skills related to their chosen engineering subject, but to also develop team working, time management, self organisation and decision making skills that will enable them to work effectively as engineers in the real world after graduation. These important transferable skills are highly sought after by industry and any chance to identify where such skills have been successfully used during an undergraduate degree course is a valuable addition to a student's CV when subsequently entering the job market.

To address the need of developing transferable skills, the School of Engineering and Design Multidisciplinary Project (MDP) was introduced in 2007 to provide first year undergraduate students with an opportunity to work together in multidisciplinary teams on a design and construction project. Each team is comprised of students from across the range of subject areas within the School and tasked with designing and building a robotic vehicle to tackle an obstacle course. The basis for the kits provided to each team are Lego Mindstorms robots for a majority of groups while the remaining groups are provided with a Parallax Basic STAMP 2 chip and a micro-controller chip to design their vehicle around. Figure 1 shows a selection of the 50 completed project builds from the 2009 MDP, showing the wide array of designs produced by the students.

This paper describes the main aims of the MDP and gives an overview of how it has developed over the last three years to become a key part of the engineering undergraduate programme at Brunel University.

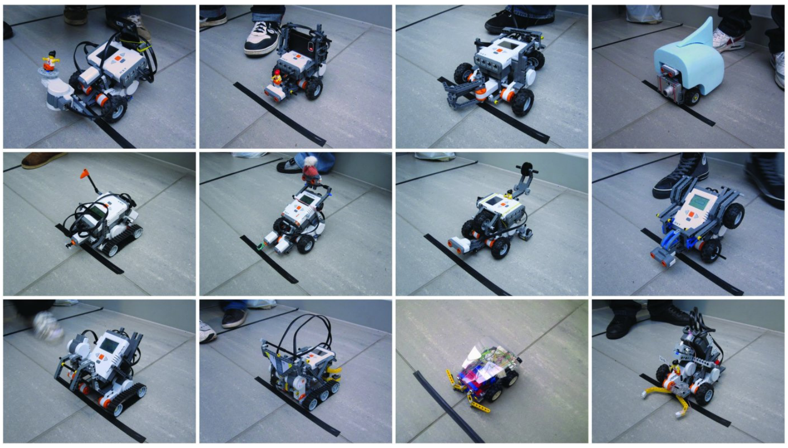

Figure 1. A selection of the wide variety of completed robots from the 2009 MDP

Keywords

Multidisciplinary; undergraduate project; large group teaching; transferable skills development

Introduction

The School of Engineering and Design Multidisciplinary Project (MDP) is a week long project based activity involving first year undergraduate students from across the School subject areas of electronic and electrical engineering, computer systems engineering, mechanical engineering, civil engineering and design. The MDP was developed as a teaching activity that would remove the barrier of academic ability to taking part by involving a non-discipline dependent technical element, the primary emphasis being on the utilisation of problem solving skills that students have begun to develop in their first term at university. Working together in mixed discipline teams would also allow the students to gain an appreciation for the many other branches of engineering there are outside their own field, many of which they will need to work closely with in industry.

A number of similar projects have been developed in the US where multidisciplinary undergraduate projects are a necessary requirement for degree courses to be accredited by ABET (Blandford et al., 2001, DePiero and Silvovsky, 2007). Although multidisciplinarity in undergraduate engineering courses in the UK and Ireland is not currently a requirement for degree course accreditation, there are a number of examples of universities incorporating multidisciplinary aspects into undergraduate project activities to address the needs of industry. Cambridge University provide a multidisciplinary 'Integrated Design Project' for level 2 students (Long et al., 2009) and a Lego Mindstorms based project activity has been successfully incorporated into the undergraduate curriculum at the National University of Ireland (Ringwood et al., 2005).

Themes and goals

Each year there are around 450 students that take part in the MDP. The students are organised into 50 mixed discipline groups of 8 or 9 students and tasked with designing, building and demonstrating Lego Mindstorms and BASIC Stamp micro-controlled vehicles to tackle an obstacle course. The 50 groups are split into five 'themes', ten groups per theme, each of which has a selection of different obstacles and hazards to negotiate on a course along with specific challenges to complete, for example: autonomous or wireless control for navigating a specific route through the obstacle course, detection and intelligent avoidance of hazards on the obstacle course, identification, collection or transportation of target objects placed on the obstacle course.

Figure 2. The MDP obstacle course layout

An overview of the technical goals for each of the project themes is given in Table 1, while Figure 2 shows two photographs of the obstacle course. The three target objects were positioned within the small black taped square along the front side of the course, students electing which of the target objects they were going to try and identify, pickup or transport at the start of their assessed demonstration run. The target objects were: a rubber egg, a small role of black electrical tape and a wooden cylinder of approximately 70 mm high and 15 mm diameter.

The technical challenge of each project theme is set at a difficulty level that all students taking part should feel is achievable, all students being able to make valuable contributions to the project work independent of their engineering discipline.

	Goals
Rover A	1. Wireless or autonomous control of a rover 2. Negotiation of a course containing a number of hazards 3. Data retrieval/analysis of a target object *Obstacle course route:* See-saw, arch, object (analysis), bridge, circular hazard, tunnel
Rover B	1. Wireless or autonomous control of a rover 2. Negotiation of a course containing a number of hazards 3. Collection and transportation of a target object *Obstacle course route:* See-saw, arch, object (collection), rubble, circular hazard, tunnel
Robot A	1. Wireless control of a robot for traversing an obstacle course 2. Capable of picking up a target object 3. Transportation and delivery of a target object *Obstacle course route:* See-saw, arch, object (collection), circular hazard, tunnel, object (deposit)
Robot B	1. Wireless control of a robot for traversing an obstacle course 2. Identification and avoidance of environmental hazards 3. Identification of a target object *Obstacle course route:* See-saw, arch, object (identification), rubble, circular hazard, tunnel
Vehicle	1. Autonomous control of a vehicle for traversing an obstacle course 2. Intelligent movement based on the environment 3. Data retrieval and awareness of the local environment *Obstacle course route:* See-saw, arch, rubble, bridge, circular hazard, tunnel

Table 1. The five MDP themes and their associated goals

Information and resources

Students are made aware of the MDP from their very first week of term via a short presentation and are then given further information in the build up to the project week. All the information is available to students on u-Link, the Brunel University web-based learning software, with printed copies of information also appearing on a dedicated MDP notice board throughout the academic term. The MDP takes place in the last academic week of December each year, a week in which all other teaching activities the students are involved with are suspended to allow sole concentration on the project.

Group and theme information and project kit inventories are made known to the students a few weeks in advance of the project week, to allow students time to make contact with their fellow group members and to do some background research on what equipment and software they will be using. The goal is to encourage all the students to be sufficiently prepared and organised that they can begin work straight away when they arrive to collect their project kit and begin the team work exercise.

Rover and Robot themes have as their basis Lego Mindstorms robotics kits which include an array of sensors (touch, sound, ultrasound and light sensors), motors, wheels, tracks and additional parts that can result in a multitude of possible designs. The central control brick is programmed using Lego software on a laptop or PC, programmes being downloaded to the unit via a USB cable. The Vehicle projects use a Parallax Basic STAMP 2 chip which can be programmed to drive Lego motors via a Pololu micro-controller. A general Lego and electronic components resource is made available to all project teams throughout the MDP week, via access to an electronics laboratory from 09:00 – 17:00 each day. Figure 3 shows some of the kit information provided to the students before the project week.

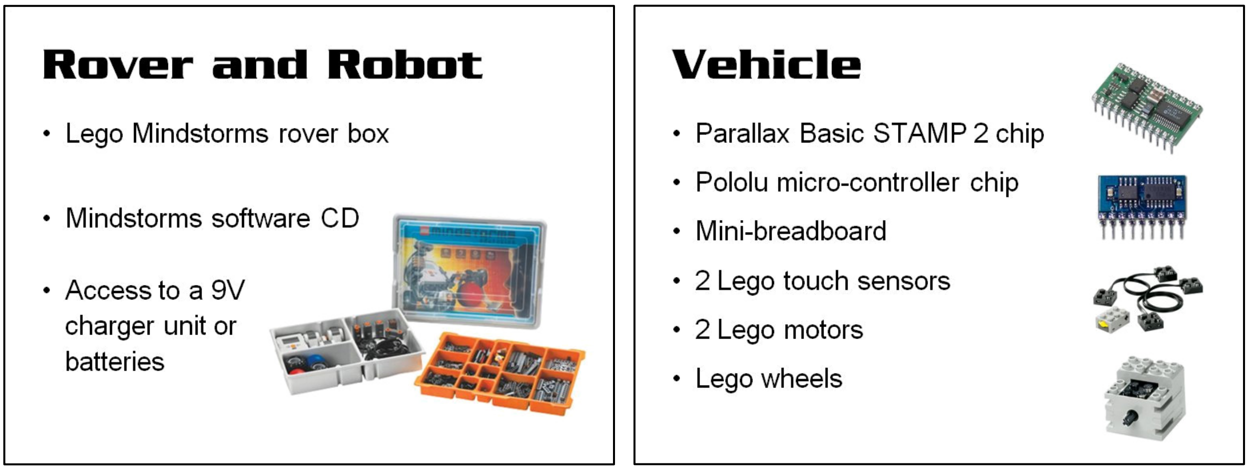

Figure 3. Slides from the 'MDP Information Pack' giving project kit inventory information

Information given prior to the project week also includes the names of members of staff available for support across the different subject areas, the location of computing laboratories with the required software installed (some of which are available 24 hours a day), the location of various laboratory and study spaces in the School that will be available for groups to work in during the project week and information about the MDP assessment components.

During the actual MDP week students are required to be present for kit collection on the Monday morning and then again on the Friday for the project demonstrations. How, when and where the students choose to work during the week is entirely down to them, the effectiveness of how well the group worked together and organised themselves being aspects of the MDP assessment.

Assessment and learning outcomes

The MDP is housed within a different teaching module in each of the different engineering subject areas, taking up the same module weighting in each case. For example, in electronic and electrical engineering the MDP counts for 25% of the first year workshop module. The stated module learning outcomes directly related to student participation in the MDP are:

- Design, build, test, evaluate, document and present small prototype systems to a given specification
- Undertake personal evaluation and reflection
- Work effectively as part of a team
- Communicate effectively in a professional manner

These learning outcomes are assessed in two parts, firstly by a group demonstration of the finished project build and secondly by submission of an individual report from each student. Each assessment component is worth 50% of the total MDP mark and is described in more detail below.

Group demonstration

Group demonstrations take place on the Friday morning of the project week, each team nominating a 'driver' for their completed robot and being assessed by two academic staff members as they tackle the obstacle course and their theme specific challenges. The group demonstration mark is assessed based on three categories:

- Analysis of the design problem (10 marks)
- Design choices made (10 marks)
- Success of the final design (30 marks)

The demonstration mark is awarded to the group as a whole, all group members receiving the same mark and grade dependent on their attendance at the demonstration and observed presence and contributions made throughout the project week by the rest of the group.

Individual report

Each student is required to submit an individual report by the end of the Wednesday during MDP week. A Microsoft Word template for the report is provided to all students, consisting of three sections that need to be completed. The three section headings are as follows:

- *Project Description* – a brief description of what your project was about and what the aims of the project were. You should include information about any background research carried out, design choices made and the reasons behind them.
- *Team Work* – a description of how your project group was organised. How was your group managed? Did you have group meetings? How were the group's activities scheduled? How successfully did your group work together as a team? Were there any problems encountered and how did you overcome them?
- *Personal Contribution* – a description of your individual contribution to the project. Comment on the success, or otherwise, of your contributions and of the project so far. Do you think all of the original goals of the project will be achieved? What would you change or do differently if repeating the project?

The submitted report is then assessed on the following categories, the first three corresponding to the three report sections given above, the final category being self explanatory:

- Critical evaluation of the technical design (10 marks)
- Reflective review of how the team worked together (10 marks)
- Reflective review of personal contribution to the project (20 marks)
- Quality of the written work (10 marks)

Feedback on both the demonstration and individual report aspects of the MDP is provided, detailing a mark in each of the assessment categories along with supporting written comments and a final overall grade in each case.

Project demonstration day

The MDP obstacle course is set up in a large indoor area with several viewing levels that can accommodate the multitude of students and staff that come to watch the demonstrations. Taking place on the last day of term, the demonstrations allow staff and students to get together one last time before the winter academic break, providing most students with a good story to tell when they go home to visit friends and relatives. The atmosphere is always very good throughout the presentation day, with students cheering each Rover, Robot and Vehicle as it makes its way out of the tunnel and heads towards the course finish line. The excitement is highlighted by the addition of a competitive element, a prize being awarded to the best demonstration in each of the five themes. A selection of Robot theme projects from the 2007 MDP is shown in Figure 4.

The obstacle course is set up from the start of the MDP week to allow students to test their designs and is a hub of activity for the whole five days. Over the last two years the School has held open days for prospective engineering students during MDP week and a visit to the obstacle course to see the students working on their projects has become part of the tour, receiving positive feedback from parents who get to see what is going on.

Figure 4. A selection of Robot theme projects from the 2007 MDP

To give an idea of how the project demonstration marks are calculated it is worth contrasting two projects, one that obtained a very high group demonstration mark (grade A, 85%) and another that obtained only a threshold pass mark (grade D, 44%). The grade A project from 2009 was particularly impressive in that its design incorporated many elements that were not to be found in the general build manual present in the Lego Mindstorms kit. The group had opted to use a free rolling plastic ball as the rear 'wheel' of their Rover which greatly enhanced the manoeuvrability and enabled the Rover to easily traverse the obstacles on the demonstration course without hitting walls or falling off edges. The Rover B task of collecting and transporting one of the target objects was also achieved flawlessly by the use of a well designed motorised claw. The claw included a finely controllable gearing mechanism to open and close the pincers along with metallic attachments on the end of each claw that detected the successful collection of the wooden cylinder target object. This project demonstration clearly showed that the group had successfully analysed the original design problem and made sensible and novel design choices which resulted in a smooth run around the obstacle course.

In contrast, the grade D project from the same year was a cumbersome design very closely resembling the base unit design provided in the Lego Mindstorms manual. The Robot did not perform well when tackling the obstacle course and got caught up on the see-saw (not enough ground clearance), crossed the boundary of the circular hazard several times (poor steering control) and struggled to get through the tunnel (no use of sensors to detect the tunnel walls). The grabbing mechanism incorporated on the front of the Robot was also not designed to be strong enough or wide enough to physically hold the chosen Robot A target object (the rubber egg). These factors were strong evidence that little analysis of the original design problem had been carried out by the students and poor design choices had been made during the project week, the group allocating little or no time to trying out their Robot on the obstacle course and interacting with the different possible target objects.

It should be noted that no clear correlation has been found between a low group demonstration mark and a low individual report mark, students being able to describe their own design choices and ideas (that may or may not have been incorporated into the final project build), problems they encountered during the project week and provide suggestions for how they could have worked more efficiently and effectively in their team, independently of the success or otherwise of their group project demonstration.

Variations on a theme

The MDP has seen a number of changes over the last three years but the key aim of developing the transferable skills of Brunel University engineering students has endured. In the first year there was an additional project theme, ‘Rocket’, that involved teams making small model rockets and putting some type of sensor into the egg shaped nose cone. Wireless cameras were provided to each team as a default payload however some teams opted to include other types of sensor, such as an accelerometer or thermometer. Although the assessment of the project was purely based on the build of the rocket and demonstration of a working payload on the ground, all ten rockets built that year were successfully launched on an extremely cold December day on a university playing field. This project theme, although being arguably the most exciting and challenging of the different projects, was dropped after the first year for primarily weather reasons but also because of the need to clear the rocket launches with local airports. In the subsequent two years of the MDP all projects have been indoor obstacle course based to ensure all demonstrations can actually take place.

It is worth pointing out that trying to organise a multidisciplinary project that fulfils assessment criteria from across a range of subject areas is no easy task. The initial development of the MDP was marked by a high level of staff resistance to trying something so radically different in the teaching programme and a lot of effort was required by those involved with the MDP to actually make it happen. This resistance seems to have been common across the sector for some time (Denton 1997). The only way to satisfy all subject areas involved was to place the assessment emphasis on the development of transferable skills, such that the individual report component could be marked using the same assessment sheet across all subject areas. Each year there has been debate amongst the different subject area academics about changing the emphasis of the assessment to lie more ‘in their area’ or to change the weighting of the MDP in their respective teaching modules. Such changes have so far been resisted, the whole nature of the project being ‘multidisciplinary’, with students from each subject area in each team, essentially being lost if the students are each assessed differently depending on their specific engineering subjects.

Although the core content of the required MDP individual report has not changed over the three years, the length and format of the report along with the submission date have changed each time. The current MDP year saw the report reduced to two pages in length from the original five, the students being provided with a template document to ensure certain word limits and specific content requirements are adhered to in each of the three sections. This year also saw the individual reports submitted during the MDP week rather than at the start of the January term. This ensured that the students had to think more carefully about evaluating their personal contribution to the project and how their group design was going to perform on the day of the demonstration without being able to refer back to the demonstration run itself. These modifications resulted in the best selection of submitted individual reports to date, with many more students showing successful reflection on and evaluation of their own contributions to the project than they did when submitting reports several weeks later when thoughts about the project have long since passed.

The bullet point list below is a sampling of quotes taken from individual reports submitted as part of the 2009 MDP that clearly demonstrate the main aims of the project were not only understood, but achieved by a number of the students taking part:

- “Modern day engineering projects make it mandatory for engineers to be able to function as a team and I think it is useful that we learn this at an early stage of our degree programmes”.
- “I have really enjoyed this project. I have met new people and made a few friends, learnt new things and generally had really good fun which I will admit going into this week, I didn’t think I would”.
- “Some of the group did not believe they would be able to make significant contributions with their knowledge and skills, but at the end of the week it was obvious that each individual could contribute to the project in their own way”.
- “Our group did the work successfully as a team as everyone had an opportunity to express their views, opinions and plans regarding the project”.
- “The multidisciplinary project original goal I believe was to get us ready for the real world working environment where we would have to work with other engineers to solve problems and create new things. This project showed me that I can get a task done with others even if we haven’t known each other for very long and we can discuss and agree on a task and complete it very easily if we work together as a team. Overall, I believe the multidisciplinary project to be a success because it showed me that other engineers can work together to create greatness”.

Conclusion

The MDP project continues to develop over time, with increasingly impressive project designs and demonstrations being given by the students and more students writing good reflective and evaluative individual reports each year, showing that they have learned some of the transferable skills the MDP was designed to teach them. In addition to practicing verbal and written communication skills, project students have set up groups on social networking web sites to communicate their group work activities during the project week and a number of videos taken by students and by the sensors mounted on the rovers, robots, vehicles and rockets themselves have appeared on the internet. Students have also spoken to staff about positive comments from potential employers made when discussing their involvement with MDP in job interviews.

The MDP also fulfils a number of other objectives beyond the stated learning outcomes it was initially designed to address, the project week being a lot of fun for students and staff, improving staff student relations and social cohesion across the different subject areas within the School. Many students have commented that they made valuable new friendships during the project week with students from the other engineering subject areas that they would not have otherwise had the chance to meet. With a number of students each year asking when they will get to take part in a similar multidisciplinary project again, the type of teaching activity the MDP entails certainly seems to aid in breaking down any prejudice students may have about working with colleagues outside their own narrow disciplines.

Feedback from students after taking part in the MDP is generally very positive, the key exception being students from civil engineering who feel the most 'left out' when working with the other students in their group. Discussions about trying to tackle this problem are planned before the next MDP week. One possible solution is the inclusion of a civil engineering challenge on the obstacle course, for example a bridge must be designed by each team of students to specifically allow their vehicle to traverse a gap.

Lessons learned from the development of the MDP are applicable to group work activities in later undergraduate years in engineering, an area currently under investigation within the School of Engineering and Design with regard to multidisciplinary activities in MEng level programmes. This point was noted following a recent accreditation visit to the School by the Institution of Engineering and Technology (IET), the review document from the panel stating that "The panel commended the multidisciplinary project in the first year and was pleased to learn that this concept will be developed for use elsewhere in the programmes". The MDP focus on transferable skills means that it also has the potential to bridge between Schools. Knowledge gained from the MDP is currently being applied to an internally funded research project at Brunel looking into the development of project based undergraduate teaching activities with teams comprised of students from the School of Engineering and Design and the School of Arts.

For academics considering the development of multidisciplinary undergraduate activities in engineering programmes, studies carried out by Loughborough University describing necessary planning measures for undertaking such activities (Denton, 1997) and documentation describing a large array of project based teaching activities by the Project Based Learning in Engineering consortium based at the University of Nottingham (PEBL Consortium, 2003) are recommended reading.

References

Blandford, D. K., Hwang, D. J., Richardson, A. (2001) *LEGO 101: A Multidisciplinary Freshman Team Experience*. Proceedings of the 2001 American Society for Engineering Education Annual Conference and Exposition. Albuquerque, NM, June 2001.

Denton, H. G. (1997) *Multi-disciplinary team based project work: planning factors*. Design Studies, 18(2), 155-170.

DePiero, F. W., Slivovsky, L. A. (2007) *Multidisciplinary experiences for undergraduate engineering students*. Proceedings of the ASEE Annual Conference. Honolulu, HI, June 2007.

Long, P. J. G., Matheson, J. M. R., Palmer, P. R., Parks, G. T. (2009) *1B Integrated Design Project: Mobile Robot*. University of Cambridge course manual.

PEBL Consortium (2003) *A Guide to Learning Engineering Through Projects*. University of Nottingham report 43/99 PEBL: Project Based Learning in Engineering.

Ringwood, J. V., Monaghan, K. and Maloco, J. (2005) *Teaching engineering design through Lego Mindstorms*. European Journal of Engineering Education, 30(1), 91-104.