Abstract

At the University of Queensland, mechatronic engineering is introduced to first year students through a project-based subject in which students design and build a robot to play Robo-Cricket. The aim of the subject is to introduce students to engineering design and, most importantly, to the range of personal and interpersonal skills required to complete mechatronic engineering projects. The implementation of this subject has been based on recent studies of collaborative learning in an engineering educational context. Particular attention has been paid to achieving a balance between student stress and student motivation.

As well as a review of the educational considerations, the paper describes the technical resources used and the task assigned the students. Evaluation data is presented that shows high student motivation and mastery of the technical skills. The data also shows student appreciation of the importance of management skills to mechatronic engineering practice.

1 Introduction

At the University of Queensland, a course entitled “Robot Design Project” has been in the first year engineering curriculum since 1995. The project involves teams of three students building robots that can play a simplified version of cricket: Robo-Cricket. Each team of students is given a bag of mechanical construction blocks, a microprocessor board and some sensors, as well as access to a PC with a development environment. The students have thirteen weeks to design, build and debug their robotic creations, with occasional guidance from a final year student mentor and series of workshops that provide technical background. At the end of the semester, the students compete in a Robo-Cricket contest where the robots play off in a round robin contest to determine the best robot design. A complete description can be found on the subject WWW page [8].

The robot design project is a powerful educational setting for introducing engineering students to the principles of mechatronics. The students are exposed to more than just the technical skills of the mechanical and electronic engineering disciplines. The robot building experience requires students to develop
1. the ability to acquire and apply new knowledge,
2. practical and experimental skills (tinkering skills),
3. the ability to plan,
4. teamwork skills, and
5. interpersonal communication skills.

These are skills that assist professional engineers throughout their careers in any discipline, but are particularly relevant to mechatronic engineering [1].

This paper addresses the educational considerations for designing a course that emphasises these deeper personal skills. This leads to a description of the educational framework of the project, as well as the technical resources used in the project and the details of the project requirements. Finally, an evaluation of the course’s effectiveness in light of student and staff feedback over the two year period is given.

2 Educational Considerations

In engaging a team-based paradigm, it is important to recognise issues in the design of team-based activities. Simply placing students in a team is not sufficient. Careful planning can greatly enhance the value of the exercise. This section describes an educational framework that is designed to enhance the value of group based teaching.

An underlying theme in design of the educational framework is the balance of student stress levels. Students who are overstressed lose motivation, take inappropriate shortcuts and resort to shallow learning techniques to “just make it through”. A lack of stress in a
project subject means that students will not rely on good planning and group synergy, and hence will not develop the personal and interpersonal skills that are a major aim for the educational outcomes.

This section describes the framework used to encourage good time management and teamwork practices, while reducing the stress levels of the project to a point where students can enjoy what is intended to be a “fun” subject. The framework addresses issues such as group formation, a student mentor scheme, positive interdependence techniques, task selection, communication fora and assessment.

2.1 Group Formation

When addressing the nature of groups for a team project, there are two key considerations: group size and group membership.

Johnson et al. [2] recommend a group size in the range of two to four students. Mourtos [5] notes that larger groups bring a range of expertise and extra hands to do the work, but require more advanced management and communication skills. A group size of three was encouraged, but groups of four were allowed. Larger groups would most likely make the project management exercise too difficult for first year students.

Johnson et al. [2] recommends enforcing a heterogenous group structure, with heterogeneity in terms of age, sex and cultural background. It is recognised that self-formed groups will tend to be homogeneous. Mourtos [5] also encourages heterogeneity, but recognises the value of homogeneity in making students comfortable to perform group tasks. Given the need to balance student stress against project realism, it was decided to allow students to form their own groups. This was based on the assumption that students are more likely to investigate management skills with their friends rather than an assigned group.

2.2 Student Mentor Scheme

Given the inexperience of the groups with both the technical and project management aspects of the problem, each group was assigned a mentor from the final year student body. The role of the final year mentor was to provide management support, not to provide technical input to the problem. In this capacity, the mentors helped the students to plan the progress of the project and to allocate tasks to individuals.

This scheme had a bonus: the final year students gained credit and practical experience for their final year management subject.

2.2 Positive Interdependence

A team project provides the opportunity for positive interdependence in a group. Mourtos [5] contrasts the groups that “divide-and-conquer” the problem to those that work together on each part of the problem. The “divide-and-conquer” approach precludes the possibility of a synergistic outcome. When students work together on problems, they can feed ideas from one another and possibly build a better solution in a shorter time. Newell [6] points out that students find it difficult to develop positive interactions in team environments, as they have educated in an ethos of schooling where competition is the norm. This competitive practice does not prepare them for cooperative tasks in the future, and makes it difficult to work synergistically in a team project.

Johnson et. al. [2] suggest three schemes for encouraging interdependence:

1. Materials Interdependence - provide only one set of materials with which to work.
2. Information Interdependence - make the students rely upon each other’s specialist skills or knowledge.
3. Interdependence from Outside Enemies - make the students compete in an intergroup tournament.

Mourtos suggests a fourth approach: Reward Interdependence. Students become interdependent when they are assessed on all parts of the cooperative design. That is, a student’s mark is affected by the performance of the other group members.

The structure of the robot design project provides Materials Interdependence (there is only one set of resources, that remain in the lab) and Interdependence from Outside Enemies through the end of semester contest. Information Interdependence tends to develop throughout the project as students interface separately designed components into the single functional robot. Reward Interdependence will be addressed further in the discussion of the assessment scheme.

2.3 Task Selection

A key issue in the design of a team project is the choice of task. Landa [3] describes a list of elements that should be present for a team based project to succeed. Tasks should:

- "result in a product of mutually agreed upon value,
- be sufficiently complex to engage all the learners and provide and active role for each of them,
- be capable of completion with the resources at hand, and
- be sufficiently structured to facilitate orderly participation."
The structure of the task and its relation to these criteria is discussed in the subsequent section that describes the task in detail.

Johnson et al. [2] stress the importance of clearly defining the task and removing any ambiguity from the task description. It is also important to clearly define the criteria for success and the various levels of success at that task.

### 2.4 Communications

There are eight workshops that deliver and develop technical material relevant to the construction of the robot and the effective use of the resources supplied. These workshops are accompanied by a comprehensive set of workshop notes that are given to the students on day one. Early delivery of this material allows students to proceed at their own pace if desired, and makes attendance at the workshops optional (most students attended). The first of these workshops is used to clearly define the task. The task is defined by a set of competition rules which are written in the notes and did not change during the semester. Accompanying the rules was a comprehensive set of criteria for assessment of performance as described in the next section.

Each week, the mentors and students meet for a progress meeting scheduled in their own time. These meetings are minuted and forwarded, along with regular progress reports. These reports served to highlight specific problems that may be facing individuals or groups.

The students are required to write two reports on their project. The structure of the reports is designed to encourage good engineering practice and form part of the assessment. These reports also highlight areas of difficulty for students and groups.

Naturally, the students also develop improved interpersonal communication skills through the practice gained in this subject. In their study of engineering college graduates, Vest et al. [7] recommend implementing communication education around a “project that anticipates the workplace”. The task-based approach adopted in the design project reflects this practice.

### 2.5 Assessment

The assessment for the subject was carefully defined before the beginning of the project. For each method of assessment, the students were supplied with detailed description of the criteria to be used. The criteria were chosen to be as specific as possible, to an extent that separate examiners would generate the same or very similar marks. Accompanying these criteria was a list of typical performance in each of the grade bands. With this clear description, students were usually able to anticipate their own marks.

The assessment was heavily biased towards the performance of the robot. Rather than separately and qualitatively evaluating fuzzy concepts such as the “elegance of the design” and the “neatness of manufacture”, an assumption was made that good designs would perform well and robustly. Furthermore, it was felt that groups that managed their time well and developed good team practice would produce robots that performed better -- again eliminating the need for an artificial evaluation of management practice. To reflect this belief, 50% of the total mark was derived from the performance of the robot on competition day. Performance of the robot was measured against the specified criteria, not necessarily on the level achieved in the contest.

The remainder of the mark was split between the two reports (10% each) and the mark given by the mentor (30%). The mentor mark was the only individual mark assigned in the assessment scheme, all other marks were applied to the whole group. This enforces Reward Interdependence. The majority of the mark (70%) relies on the whole team functioning together. The individual marks were assigned in recognition that some individuals may unfairly leave the work to others. This “passenger syndrome” is often a criticism of team-based work, and further comments will be made in the evaluation section.

### 3 Technical Resources

The students who participate in the robot design project are fresh from high school, most with no experience in mechanical design, programming or electronics. Yet they must become sufficiently competent in each of these mechatronic disciplines in a thirteen week period. In order to simplify this learning task, the students are given building blocks for each of these three disciplines. The mechanical, electronic and software building blocks are at an appropriate level of technical sophistication to allow the rapid prototyping of a complete robot while presenting a minimal technical learning curve for the first year students.

#### 3.1 The UQBOT Board

The central resource used by the students is the UQBOT board -- an experiment board based on the Motorola MC68HC11 microcontroller. The board is
shown in Figure 1. The board is supplied by a 7.2V rechargeable battery pack, and can be run from an external power source. It is interactively programmable using a PC. The public domain software used for this interactive programming is described in a later section. The board can drive two motors with PWM speed control as well as direction control. Robots built with this controller can run in a completely autonomous fashion, with no external control cables or power cables.

![Fig 1. The UQBOT board used as the basis of the electronic component of the robot design.](image)

The students manufacture the board themselves, following a set of written instructions and a tutorial on the use of a soldering iron. The students are required to maintain their board throughout the semester. In the event of damage they are supplied with diagnostic help -- but they must make the repairs themselves. This experience benefits students who do not have the tinkering experience that many engineering students had twenty years ago. The hands-on work is a first insight into issues such as manufacturability and reliability.

On the right hand side of the board depicted in Figure 1, there is an array of three pin connectors. Each connector has a power, ground and signal connection, making them suitable for interface to simple sensor modules that the students design and build. The connectors can be programmed as analog inputs, digital inputs or digital outputs. Two specialised connectors can also be used to read shaft encoders. The students are supplied with a range of sensors and peripherals that are suitable for connection to these interfaces, as well as instruction in the manufacture of the electronics. In addition, the students are invited to design and build their own electronics. The plug-on design of the board allows sensors to be easily modified or reallocated for new sensor configurations.

3.2 Software

The students use the public domain C interpreter “Interactive-C” to develop their programs. This software was developed by MIT, and is freely available for educational use. The interpretive nature of this programming environment allows students to test code fragments experimentally, without the need for an extensive test harness.

The environment is supported with a software library developed for use with the UQBOT board. The library allows students to use the many features of the MC68HC11 without resorting to “bit banging”. For example, a student can read the analog-to-digital converter using a simple statement like:

```c
value = analog_in (PORT1);
```

without the need for any knowledge of the internal workings of the microcontroller. The library also provides routines for speed and direction control of the motors, timing, multi-tasking, shaft encoder capture and the speaker.

3.3 Mechanical Design

![Fig 2. LEGO™ DACTA™ components are used for the mechanical layout of the robots.](image)

The use of LEGO™ components for the mechanical design of the robots gave students the freedom to explore many different mechanical configurations -- just as the modular nature of the software encouraged exploration of different programming approaches. The students were forbidden to use any mechanical components other than those supplied in their bag of blocks given at the start of semester. Within these constraints, students were able to build mobile robots, robot arms, ball shooters and even multi-configuration robots that could change between
being mobile or fixed as the occasion demanded. Such a robot is shown in Figure 2.

4 Playing Robo-Cricket

The choice of building blocks, combined with the Landa’s criteria for task selection [3], form the basis for the task to be performed. The students were to build autonomous robot to compete in a round-robin competition of Robo-Cricket.

4.1 Summary of the Rules

In Robo-Cricket two robots play against each other. One robot is called the "running robot" which will try to score as many runs as possible by running up and down the pitch. The other robot is the "fielding robot" which has the more complex task of fielding a metal ball which it must hit against the stump in order to get the running robot out. The running robot tries to score as many runs as possible before the fielding robot hits the stump with the ball. Figure 3 shows the cricket field with the robots ready to start.

Fig 3. The cricket pitch used for Robo-Cricket with two robots in start position.

The pitch is the white line running up the middle of the field. The stumps are the two silver objects at either end of the pitch. They each have a beacon that tells the robots when to start running, and to which end to run. Also at each end of the pitch are two creases monitored by electronic umpires that detect when the running robot crosses the crease. The umpires are used to automatically control the beacons and detects when the running robot is out. The running robot is shown starting from the near crease, with the fielding robot starting in the designated fielding box. The ball is in the small square in front of the fielding box.

Unlike real cricket, Robo-cricket is played as a full-contact sport. In fact, the rules encourage contact between robots. For example, the fielding robot may attempt to ram the running robot off the pitch, hoping that the robot will not be able to find the pitch to resume running.

Full details of the rules can be found on the WWW [8].

4.2 The Suitability of the Task

The task was designed with the criteria set by Landa [3] in mind. This implies that the task should be relevant to the practice of the students -- mechatronic engineering. Clearly building an autonomous robot of any nature satisfies this requirement.

The task had to be large enough to give each team member something to do, while still being possible with the available resources. This is where the design of the game becomes relevant. The game had to be sufficiently complex to challenge the students and create a reasonable workload, while still being playable using simple sensors (such as reflected infra-red detectors, beacon detectors and bump switches) and only two motors.

Finally, the task had to be rich in modularity to allow a division of labour amongst the group. The task can be split in any number of ways, with members concentrating on particular disciplines (programming, mechanical layout, electronic design) or perhaps on aspects of the task (running, fielding, ramming).

In addition to Landa’s criteria, it was felt to be important to encourage a multitude of approaches to the problem. Students were most ingenious in developing novel solutions to the complex task of playing Robo-cricket. They quickly moved away from the idea that there was one “correct” answer or technique for solving this problem. They saw merit in many of the approaches used and learnt the importance of trading off design criteria in an effort to achieve the most effective product.

5 Evaluation

After two years, considerable data has been gathered with respect to the effectiveness of the robot design project as an appropriate educational tool for training mechatronic engineers. The data has come a variety of sources including student questionnaires, student reports, reports from the final year mentors, formal and informal discussion groups with students and mentors and from the lecturer’s experiences with individuals and groups.

The data shows that students are capable of mastering the technical knowledge quickly, and are highly motivated by the nature of the problem and its educational context. This was apparent from the high degree of sophistication and reliability found in the
robots that students constructed. The more difficult task is to evaluate the success of the educational framework in developing the deeper personal and interpersonal skills required of a mechatronic engineer.

5.1 Self Management Skills

The data showed that the nature of the project emphasised the need to function as a synergistic group. The structure of task and the educational framework provided sufficient positive interdependence to encourage students to explore strategies in teamwork and time management. The mentors provided guidance in this aspect of the project. In general, the students developed an appreciation of the importance of teamwork and time management skills in mechatronic engineering practice, even if they did not master the skills during the project. The student reports contained statements such as:

“In a project such as this, it can be quite difficult to align working as a team, especially if it is one’s first time at doing so.”

“If we were to repeat this project, or a similar project, the major difference would be in our management approach.”

“We need to improve our skills in time-management and planning.”

It is interesting to compare this to the experience of our recent graduates. A recent survey [4] showed that 89% of our graduates believed that practical project management skills should be more emphasised in the course. By acting as a real world simulation, the robot design project has brought our students to a set of beliefs that correspond closely with our older and more experienced graduates.

3.2 Identifying Dysfunctional Groups

Generally the group structures worked well, validating our choices for group formation. However, close attention was paid to the small number of dysfunctional groups. These groups were characterised by one individual taking on a large portion of the project, with the other members sitting back and letting that person dominate the project. Typically, the members of the group who did not participate would be branded indolent: the “passenger syndrome” discussed earlier. Upon closer inspection, it was found that this was rarely the case. The students who did not participate were not doing so out of laziness, but usually for a number of reasons relating to the behaviour of the dominating individual.

Dominating individuals can take ownership of the project excluding the other members of the group. Such individuals will then tend to treat the other members as lackeys who are to do the lesser tasks in the project. Naturally, the other members of the group lose motivation and participate no further. It is important then to recognise that the passenger syndrome can often be due to the overwhelming behaviour of dominant individual, rather than the indolence of the passengers.

This issue is being addressed by changes in the assessment scheme and a modification in the role of the mentor. These changes emphasise reducing rewards for dominant individuals rather than punishing passive group members.

In summary, Robo-cricket has been a successful experiment in the education of mechatronic engineering. It has provided exposure to the key technical disciplines of mechatronics, while at the same time providing valuable experience in the management of a multidisciplinary project.

References