Student-centred Activity-based Learning within a Mechatronics Degree Course

Robin Bradbeer, Department of Electronic Engineering, City University of Hong Kong, Hong Kong
E-mail: EERTBRAD@CITYU.EDU.HK

and

K. P. Rao, Department of Manufacturing Engineering, City University of Hong Kong, Hong Kong
E-mail: MEKPRAO@CITYU.EDU.HK

Abstract

The introduction of the Honours Degree in Mechatronic Engineering at City University of Hong Kong in 1992 provided a unique opportunity to consider new approaches to teaching mechatronics.

In the 60s, 70s and 80s, Hong Kong's main employment came from light, low tech, manufacturing. In the 90s this has mostly moved to southern China. Hong Kong is moving towards a management, financial and skills centre for the Pearl River delta. This means that engineering education has to be more aware of these roles. Therefore new subjects, and ways of teaching them, must be introduced into the academic curriculum to meet these new demands.

The first part of this paper looks at the manufacturing environment in Hong Kong. The second details the development of the Mechatronics degree and the use of student-centred activity-based learning. The third part looks at other mechatronics group-based learning activities such as Micromouse and robot ping-pong.

1. INTRODUCTION

In the last 30 years, Hong Kong has developed into one of the major manufacturing centres in the world, and it has moved towards higher quality products. There is a general awareness that unless Hong Kong modernises its industries and moves up-market to higher value added products, Hong Kong will not be able to withstand global competition, especially from the other dragons and the developing countries. The need for such a transition is further underlined by the rapid erosion of Hong Kong's advantage in terms of lower wages, the transfer of low-end manufacturing operations across the border to China, and the rise of the service sector in relation to the manufacturing sector.

Thus, the manufacturing industry in Hong Kong has seen significant modernisation through two parallel developments. First, many computer based manufacturing technologies have been adopted by local industries. As a result, processing machinery in many local industries is becoming more and more mechatronic. Traditional mechanical or electronic engineers are unlikely to be adequately equipped to man such installations, and there is an urgent need for mechatronic engineers to adequately support this growing trend in the local manufacturing scene.

Secondly, Hong Kong industries seem to be moving beyond the long tradition of manufacturing OEM products [1]. With the substantial growth in the electronic products manufacturing sector in Hong Kong, many industries have embarked on in-house design activities. Thus, while Hong Kong continues to produce for overseas brand names, much of the downstream product development activity is being progressively transferred to Hong Kong. Even in industries dominated by OEM products, much redesign work goes into fine tuning the design in order to meet the requirements of the local manufacturing facilities. Since design is the most value-added component of the design-make cycle, it can be anticipated that the trend towards increasing local design content will be accelerated in the future.

The aforementioned beliefs have been largely confirmed through a survey of local industries undertaken during 1990-91. The industries surveyed included those involved in consumer electronic products, electronic instruments, machinery, mould making and speciality equipment. The major findings of that survey were as follows. Most of the companies surveyed:

* perform some level of in-house design.

* expect more high-value-added products to be designed and manufactured locally in the near future as competition is becoming stiffer among the neighbouring countries.

* emphasised the need for broad based engineering training in Hong Kong and, in particular, stated that design engineers should know more about the manufacturing aspects of product development.

* highly value the importance of 'Mechatronic Engineers' (as defined and explained by the interviewers) since their products are becoming more and more sophisticated.

A number of companies are using sophisticated 'mechatronic' equipment and/or are engaged in the in-house design of special purpose manufacturing equipment involving 'mechatronic' manufacturing strategies.

Therefore, from the industrial viewpoint, a mechatronic engineer should be particularly useful in:

(a) Product mechatronics: i.e. in the design of mechatronic products, and

(b) Process mechatronics: i.e. in the utilization, operation and maintenance of mechatronic process machinery - mainly in the manufacturing industry.

Product mechatronics could be further subdivided [2] into:

(a) Consumer products - which tend to be mass produced, have shorter life cycles, and have greater pressures on cost, and greater requirements in terms of aesthetics; and

(b) Engineering products - which tend to be technically much more complex.

The knowledge elements required for both these sectors overlap substantially. However, the design of consumer products involves many other aspects like industrial design, manufacturing engineering and marketing.

Both the Departments of Manufacturing Engineering (ME) and Electronic Engineering (EE) at City University of Hong Kong (CityU) were aware of the need for introducing group-based activities where students could explore all aspects of the design process. This led to the conception of a Mechatronics Degree.

2. THE MECHATRONIC ENGINEERING DEGREE COURSE

2.1 Introduction

Using the results of the survey, given above, and working in collaboration with the Department of Electronic Engineering, the Department of Manufacturing Engineering at City University of Hong Kong developed the Mechatronic Engineering Degree course.

From the viewpoint of Hong Kong [3], the primary need for mechatronics is in the context of consumer products and manufacturing processes, which has largely driven the development

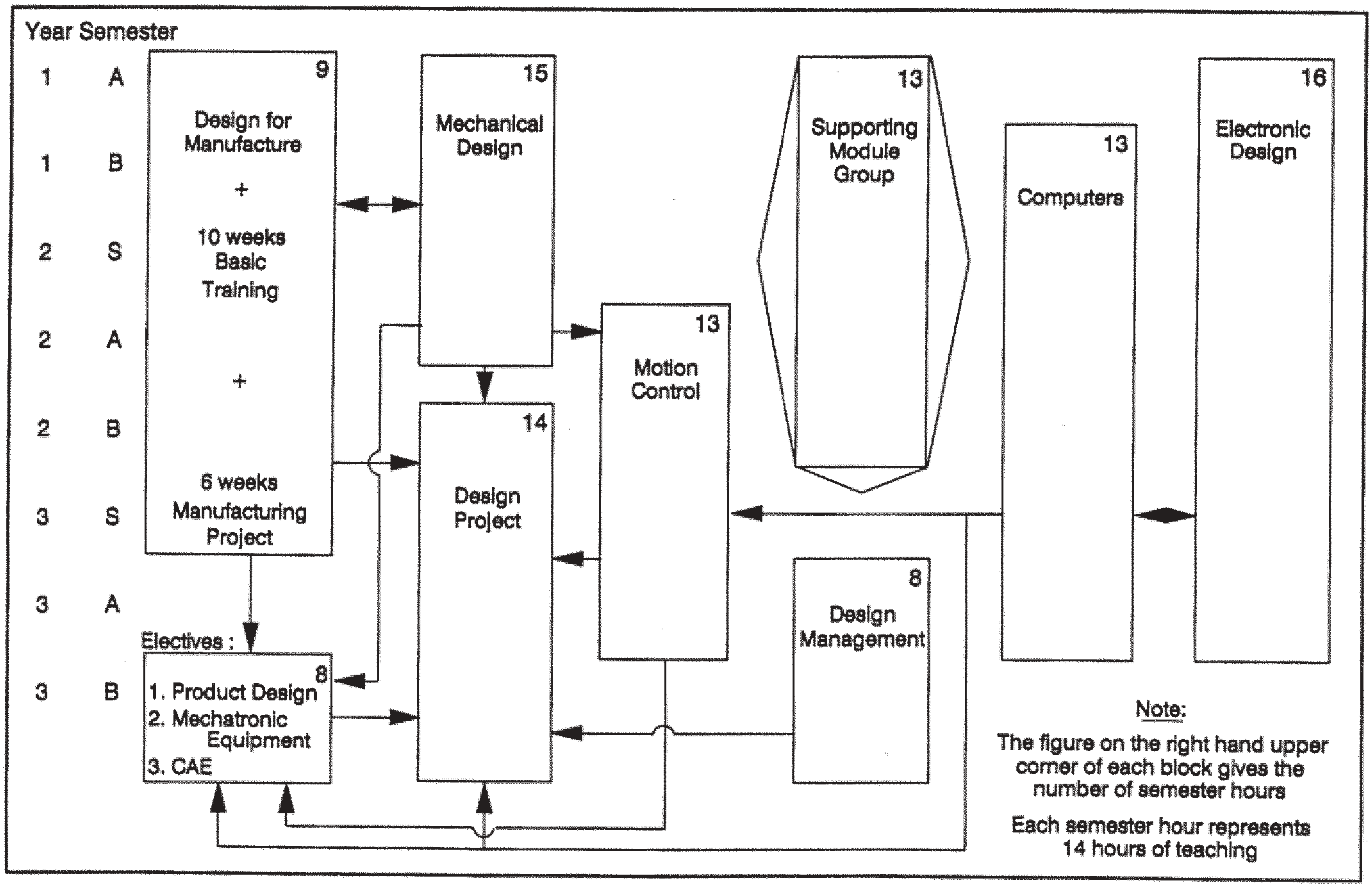

Figure 1: Interactions between module groups

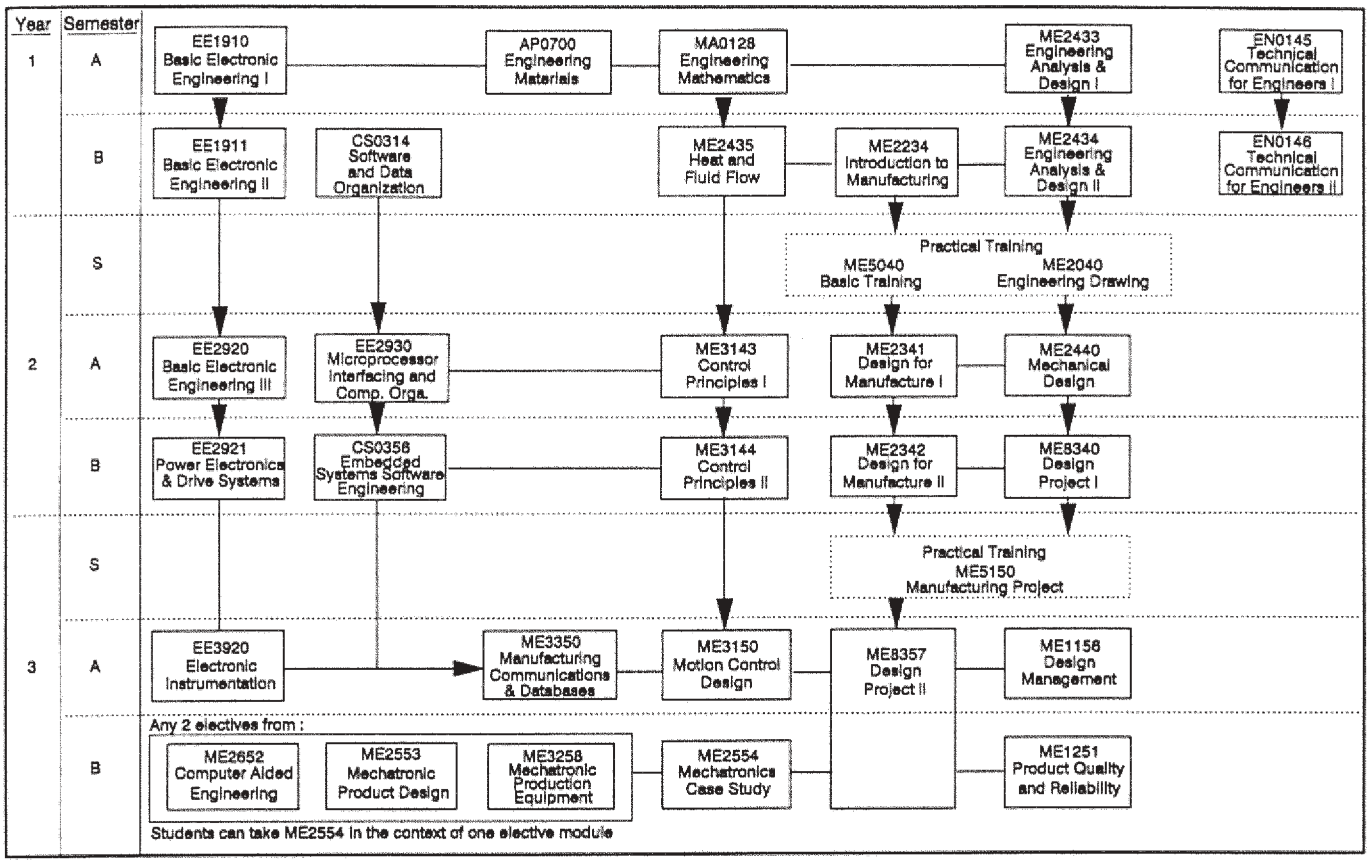

Figure 2: Module organisation and flow of BEng(Hons) in Mechatronic Engineering

of the degree course. The course aims to produce mechatronic engineers who are capable of integrating the diverse disciplines of mechanical, electronic and computer engineering with a view to :

(a) designing and developing high value added discrete products of mechatronic nature, and

(b) implementing the engineering aspects related to utilization, operation and maintenance of flexible manufacturing equipment and systems.

In the context of the present course, the study is focused towards the development aspect of engineering design, which was neglected over the years [4,5].

The course design principles and the objectives chosen were reported earlier by Venuvinod and Rao [2]. The course is divided into three years of study. Figure 1 shows the curriculum of the mechatronic engineering course in terms of 9 module groups or themes, along with the sequencing of and the interactions between the different module groups. Figure 2 shows the module organization and flow. A detailed description regarding the subject material being dealt within each module of each theme and the role of each theme can be found in earlier publications by Venuvinod and Rao [2,3].

2.2 Learning Methods

In keeping with the special requirements of the study of design, the course has a significant proportion of time devoted to 'active learning' through 'doing' as opposed to 'passive learning' through attending lecture sessions. Thus some 65% of the total contact time in the course is devoted to laboratory, project, tutorial and training components where the student is largely in the active learning mode. The course has 322 hours of laboratory (excluding the 196 hours of design project work) where students undertake a mixture of structured experiments and student centred activities centred around practical mini-projects.

The two System-level Application and Integration Laboratories (SAILs) -- a flexible machining system and a flexible assembly system developed in the Department of Manufacturing Engineering -- being essentially mechatronic in nature provide a fertile ground for such active learning exercises and for generating in-house developed case material for discussion during tutorial sessions. Practice in the design process itself extends over the entire course - starting with Engineering Analysis and Design in Year 1, followed by Mechanical Design in Year 2 and then through the Design Project extending over the rest of Year 2 and the entire Year 3. Much of this activity is done in groups thus simulating the team environment in which design projects are typically executed in the industry. The SAILs and the support expected from local industries should enable the assignment of design tasks with realistic objectives and constraints.

A design office is developed which is equipped with design manuals and standards, industrial catalogues and drafting equipment in order to provide a proper learning environment. The Unigraphics II system, the AutoCAD system and several other CAE packages available are of particular help to students undertaking complex design tasks.

2.3 Student Centred Activities

As mentioned earlier, it is the intention of the course to promote 'active learning' through student centred activity (SCA). This reflects the belief that students learn best by doing. Learning through lectures is essentially 'passive' since it does not develop the ability to apply and integrate the knowledge derived. In order to facilitate the inclusion of substantial student centred activity, the lecture content in the course is restricted to about 50% with the balance being devoted to tutorial/laboratory/project work. While some student activity time may, of necessity, have to be spent on the consolidation of the concepts learnt in the lecture sessions, there is significant scope in the course for undertaking planned student centred activity.

There are a number of major opportunities for active learning in the course: the assignment of open ended problems in the various tutorial and laboratory sessions throughout the course, Basic Training, the Manufacturing Project, mandatory SCAs in four major modules, mechatronics Case Study and the Design Project

Some of the most successful mini-projects carried out by students in their first year of study in the module Engineering Analysis and Design are -

(a) Projectile Machine: In this project, students design and build a mechanism that is required to project bullets of 20 to 33 grams to a distance of 5 to 10 metres with an accuracy of 100 mm.

(b) Power Transmission for a Vehicle: This is to design a linkage system for power transmission and a vehicle to implement it. The vehicle has to cover a distance of at least 10 metres on a flat concrete floor with a payload of 300 grams using a power source. The power is derived by converting the potential energy associated with a dead weight of 1000 grams placed at a height of 1 metre above the ground level. The vehicle should stop within a range of 0.3 metre of the specified distance.

Such SCAs are organised so that students are divided into groups of 4 or 5. Each student group is assigned a substantial open ended problem that requires the application of the subject material taught in the module.

Each student group autonomously plans and implements the solution of the problem. The role of the lecturer is limited to providing technical consultancy and monitoring/ assessing the students' performance.

An appropriate proportion of the tutorial and/or laboratory time in the module is reserved for the implementation of SCA. By the end of the module, each group submits a written report, clearly identifying individual's contribution to the group's SCA, and competes with other groups by practically demonstrating the project in a competitive environment.

2.4 Intensive Practical Training

In the Basic Training phase, the students gain an understanding of the wide range of manufacturing processes, equipment and tooling utilised in the manufacture of mechanical and electronic products in a simulated industrial environment. The learning mode is essentially hands-on operation on processing equipment in order to develop practical skills.

The practical training continues through the Manufacturing Project which is of six weeks duration undertaken in the summer term of Year 3. The project, which is carried out in a Training Centre/Facility, aims to develop the skills required in the planning and execution of the manufacture of a fairly complex mechatronic product in a jobbing environment. The students are divided into small groups and each group is provided with the full technical specifications of the product to be fabricated.

The product contains both mechanical and electronic elements. Whenever feasible, the students engage in the fabrication of a product related to, or derived from, their own Design Project or the ones completed in previous years, in which case there is some flexibility in scheduling the manufacturing activity so as to allow the completion of relevant designs and drawings. The students are expected to work in autonomous groups, plan their own work, study the manufacturing infrastructure available in the Training Centre and utilise it appropriately.

3. OTHER MECHATRONICS GROUP-BASED ACTIVITIES

3.1 Introduction

The Mechatronics Degree is not the only degree course at City University of Hong Kong to use group-based activities in teaching mechatronics related subjects.

The Department of Electronic Engineering has for some years used Micromouse and robot ping-pong as a basis of such activities.

Micromouse, as an exercise in the design and implementation of an integrated mechatronics application, has been around since 1979. However it is only during the past six years that it has been taken seriously enough by the academic community, and considered as an ideal project for diploma and degree students.

During the mid eighties a number of papers were presented at conferences in the UK [6], [7], which attempted to raise the awareness of the use of robotics in engineering education, and a number of magazines, continued to feature many articles on mechatronics based projects such as Micromouse. However it was not until the Japanese entered the ring that the full potential of a coordinated approach to Micromouse was appreciated [8].

A similar, but more low key, history applies to robot ping pong. A number of contests, especially in Europe, during the late 80s has brought the idea of robot ping pong to a wider audience. However, very few educational institutions seem to appreciate its educational uses. Robot ping pong in a similar situation today as Micromouse was in the early 80s - an interesting event but not considered much use. The World Robot Ping Pong Championships held in Hong Kong in 1992 was dominated by research orientated entries, unlike the Micromouse World Championships held the year before, which was dominated by undergraduate entries.

3.2 The engineering challenge

Micromouse is essentially a totally autonomous robot that has to solve a very particular task, i.e. map an unknown maze and then find the quickest path to the centre of that maze. For the fastest mice this means controlling around 1kg mass moving at up to 3m/s with a positional accuracy of +/- 1mm in a 9 sq m area. The individual parts of the mice are inherently very simple and easy to assemble; however the integration of these parts into a unit that can solve the control problem above is not that easy - and this is the challenge to the students.

There are basically four parts to a Micromouse. First the sensors; these can be infrared, looking either down on the walls or at the sides of the walls, laser, ccd array (vision) or ultrasonic. Secondly, the motors can be brushed dc, brushless dc, servo or stepper. Thirdly, the processor can be anything available, from microcontrollers like the 80196 to simple 8 bit processors such as the Z80. Finally the software can be written in anything from C++ through assembler to Quick Basic. Normal algorithms can be used or even fuzzy logic or neural networks.

This great diversity means that every mouse is different. The potential combinations are nearly infinite - which is why Micromouse is an ideal project to teach the integration of electronic, mechanics and control/software, ie mechatronics.

Robot ping pong, on the other hand, has rules which are less well defined. The only criteria is that the robot does not overhang the table - which is itself a cut down version of a normal table tennis table.

Any method is allowed for the vision system, as long as it does not interfere with the opposing robot. Thus stereo video cameras, rotating mirrors and even ultrasonics have been tried. At the same time the bat has been attached to a simple robot arm, vertical x-y plotter and, even, complicated metal and wood framework. Essentially the bat mechanism has about 1.5 s to respond to information from the vision system.

Robot ping pong seems to need a different approach than that of Micromouse. Interestingly the Japanese have not taken to ping pong in a similar way to micromouse; maybe the engineering challenge is beyond the capabilities of their fairly rigid undergraduate education system.

3.3 Education's response

There are a number of ways of responding to the challenge presented by both micromouse and robot ping-pong when deciding how to use them in a learning environment. The first is to have a very structured approach, where students are guided by academic staff and precedent. The other is to let students go their own ways in a flexible environment. The third is to follow a group-centred approach which married the two previous ones.

The leading proponent of a structured approach to micromouse is Ngee Ann Polytechnic in Singapore. Selected students initially follow a two week solid training programme involving software, solving and search theory, hardware and sensor design etc. Every student builds everything from scratch, code is not reused; however students' software design efforts are transferred at the flowchart level. The supervisors keep close contact and follow the students work. The best students have also created their development tools.

The Department of Electronic Engineering at City University of Hong Kong uses the other approach, which follows the more 'free-wheeling' aspects of Hong Kong society when compared to Singapore. In this programme, described in detail below, students are free to follow their own ideas, but must work within departmentally set guidelines, usually as part of a group, or at least with one partner.

California State University at Long Beach, CSULB, in the United States also has a long running programme. There are around twelve students at any one time based in the Computer Science and Engineering Department. Although originally basing their designs around a Mappy kit from Japan they have now moved on to locally designed hardware. Unlike other institutions the interest in micromouse at CSULB was generated by the local IEEE student branch's purchase of the kit.

MIT in Boston, USA has always been at the forefront of micromouse design. Their latest approach is to ask students on a robotics short course at MIT to build a micromouse using Lego parts. This approach is, in itself not new, with one of the first mice using Lego in 1980.

Finally, there is the Japanese approach. This originated with delegates from the New Technology Foundation, a government funded body set up to encourage the awareness of informatics in schools and colleges, doing the rounds of micromouse contests in the early 80s. Then they ran the first major world contest in Tsukuba in 1985, where the Japanese mice thrashed the competition. Since then they have encouraged the growth of micromouse clubs around Japan, and these now number nearly 200. The annual Japanese contest regularly attracts over 100 entrants.

On the other hand, robot ping pong has been the preserve of postgraduate students. This is because the vision system has been considered too difficult to design and construct by undergraduates. Experience at City University of Hong Kong has shown that this is not the case.

3.4 Hong Kong's experience

The Department of Electronic Engineering at the City University of Hong Kong runs four main courses, three honours level bachelor degrees, and one MSc. Two Higher Diploma (senior technician) courses have recently been phased out. In total the department has over 1000 students, approximately 400 of which are studying part-time/evening. The academic staff establishment is about 60.

Each year the department has to find around 350 projects for the final year students. Five years ago it was decided that micromouse should be a 'running' project that would be offered across all courses, on a first-come, first-served basis. The total number of Micromouse would be restricted to ten, although due to the fact that HD students did their projects in pairs, the total number of students involved has been as high as sixteen.

Two years ago it was decided to introduce robot ping-pong as another project that would run each year, although in this case the student numbers were restricted due to lack of space for such large equipment.

The number of students doing micromouse in the Department of Electronic Engineering is dropping off for a number of reasons. First, the HD courses have been transferred to the local Vocational Training Council College. However, this college now institutes micromouse as a compulsory second year mini-project for all EE students. It is expected that about 30 groups of students will take part in this work.

Secondly, the establishment of a Mechatronics degree course in ME at the University means that students are now available with a background in mechanical engineering as well as electronic and computer engineering. Some final year project students from ME have redesigned the standard chassis originally developed by Bradbeer [9]. This is now a very efficient base on which students can build. It has been adopted by a number of schools and colleges in Hong Kong.

The implications of these two expansions of interest in micromouse, especially for the Hong Kong economy are addressed below.

The majority of students have used stepper motors to drive their mice. Clearly the ease of control compared to dc motors is more important than the power considerations. This is changing, however. As the department builds up its expertise it is interesting to note that at least half of this year's students will be using dc motors. The recent acquisition of special stepper motors from Japan, specially designed for micromouse, means that much faster stepping speeds will be available in the future - up to 6000 pps. This will also tax the students' ingenuity in controlling up to 1kg travelling at up to 2m/s.

The number and type of sensors is also evolving. In the first two years of the programme all used infra red sensors looking at the top of the walls, although one group did use a focused infra red beam from the front of the mouse to detect the distance to an oncoming wall, as well as sensors on top. Recently, students have been encouraged to experiment with other sensors. These include low powered lasers to detect side walls as well as front and rear walls; ultrasonic detection for locating walls and for position control; and the use of a ccd camera. The latter project has been very successful, with the vision system able to map the whole maze from just four observation points [10].

The maze solving algorithms used range from the commonly used depth-first routine to some very esoteric ones designed by the students themselves. Although much background information is available for students to use in developing their software, supervisors do not encourage the simple copying of previously used software. For example, all previous project reports are available for novice students to study, as well as a very comprehensive library based upon copies of papers and magazine articles about micromouse published during the last 12 years.

The methods used by the students have ranged from the sublime to the ridiculous! One project used two video cameras and much signal processing to follow the ball and predict its path. This proved very successful, and was used as the basis of the robot that came third in the 1992 World Championships.

Another project tried using a system of mirrors and infra red detectors. This has not proved a very productive route to follow.

Recently the Department bought the robot that came second in the 1992 World Championships, Charlie V. This has been used as the base for some further development work. Charlie V uses rotating mirror to build up a record of the angle subtended by the trajectory of the ball. A second camera has been added to make each record more unique [11].

Collaboration with ME students means that robot ping pong has now become multidisciplinary. Just as with micromouse, a number of students from ME have also participated in the mechanical design of robot ping pong. Further development of the structure is expected in the coming year.

3.5 The pedagogic argument

Micromouse and robot ping pong impinge upon the students' training in many areas. The obvious one is the use of a simulated real life situation or problem. This allows them to come into contact with the sort of engineering problems faced in the 'real world' instead of the more theoretical simulation employed much too frequently at this level.

Micromouse and robot ping pong also give the students real problems to solve; and they have to be solved within a set time - around 40 weeks in EE's case, and within real budgets - around HK$600. These extra disciplines mirror in some way the processes involved in an industrial/commercial environment.

The integration of software, electronics and mechanical design along with the problem solving techniques involved in maze searching and solving algorithms, makes these type of projects unique, which is why they are so popular, as well as useful in teaching mechatronics.

However, within the Hong Kong context, other aspects arise. Most of the students buy the parts for their projects from one of three street markets that specialise in selling used, or 'stock lot', electronic products. Thus they have to evaluate and purchase their own components. At the same time, the fact that they are members of a team, with regular discussion between 'competing' groups, also gives an added dimension to development work that can be missed in a more traditional approach. Finally, the contests that are held locally, regionally and internationally each year provide an added incentive in the way of travel and prizes.

During the five years that micromouse has been used for final year project work at CityU thirty two mice have been built by forty three students. The integration of electronics, mechanics and software, allied with the time and cost constraints, has made each micromouse project one of the best simulations of a real life design problem.

The added bonus of working as part of a team, and also the competitive nature of the contests, has also given the students a foretaste of the commercial environment. This is not usually possible with most final year projects, and would certainly not be true if only one or two mice were built each year.

Robot ping pong, on the other hand, provides the student with a different stimulus. In this case they must consider a complicated situation and then simplify it to such an extent that a minimal solution is possible within their understanding, as well as budgetary and time constraints. The close working relationships expected with teams of students from ME courses gives the EE students experience in working with people from other, related, disciplines.

CityU's involvement in the organising of the annual Hong Kong Micromouse contest, now in its sixth year, as well as the Micromouse World Championships in 1991, and in 1995, and the Robot Ping Pong World Championships in 1992, has meant that both micromouse and robot ping pong have developed a very high profile in the territory. So much so that other institutions, from universities and polytechnics, to schools and technical institutes, have now asked for help in starting projects of their own.

The situation with robot ping pong is more complex. The perceived difficulty of the project has still to be overcome. Therefore we have decided to use this as a project to investigate collaboration between EE and Mechatronics degree students. Although in its early days, it is clear that this synthesis of approaches and disciplines offers a unique simulation of industry.

4 IMPLICATIONS FOR INDUSTRY

Any education programme that aims to be useful to the local industry that supports it has to have a balance between academic and practical work. In an Asian environment, especially one based essentially on Chinese culture, emphasis is usually given to the rote learning of bookbased knowledge.

One of the objectives of tertiary engineering education is to overcome years of preconditioning, and to get the students to think together and to work together. At the same time, introducing experimental work into the curriculum that will be useful training for industry is also important.

The changing face of Hong Kong industry during the past decade has meant that this experience is not now part of everyday life. In the 60s, 70s and 80s, Hong Kong's main employment came from light, low tech, manufacturing. In the 90s this has mostly moved to southern China.

Hong Kong is moving towards a management, financial and skills centre for the Pearl River delta. This means that engineering education has to be more aware of these roles.

Group based projects, such as the SCAs in ME and micromouse in EE, coupled with interdisciplinary ones such as robot ping pong, are one method of meeting these challenges.

The fact that vocational colleges and schools are also participating in mechatronics-based project work will enhance the appreciation of evolving and integrating technologies.

The only other country to take micromouse seriously, Japan, did so because its government saw exactly the same opportunity and need. Unlike Japan, however, Hong Kong has no centrally imposed curriculum or financial or technical support for setting up micromouse clubs. It is only the interest of members of staff at these institutions that allows such activities to flourish.

As southern China moves into higher technology manufacturing, it is clear that the same needs will arise there as arose in Hong Kong in the 80s, ie a technically advanced engineering profession conversant with up to date technologies. Student-centred activity-based learning provides a low cost, and exciting, way of getting students interested in mechatronics.

5 CONCLUSIONS

It has been shown that all aspects of mechatronic processes and design can be taught using modern concepts of activity-based learning. At CityU the Students Centred Activities in ME and the micromouse and robot ping-pong projects in EE, have been successful in giving students a sense of group working in a relatively open ended environment.

The results of these activities have been well received by both industry and students alike, and have become one of the focal points for course development.

6. ACKNOWLEDGEMENTS

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