Engineering Design in Computer Systems: An Interdisciplinary approach in the Department of Electrical and Computer Engineering at the University of Auckland

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Abstract

This paper reports our recent initiatives in introducing an interdisciplinary environment in a year three computer systems design course, as well as how the teaching of design skills is achieved. For the past two years third year computer systems students worked together with a fine arts elective group of year two to Masters students, in the final project of a full year design course. The experience gained from both sides is discussed and this new initiative is compared to other approaches in other Universities around the world and inside the Faculty of Engineering at the University of Auckland. The history of the design courses in the Department of Electrical and Computer Engineering and the School of Fine Arts is reviewed and the current course structure is examined. Results are presented from a student survey, conducted to evaluate the students' viewpoint on the course. The paper concludes with a discussion on the benefits perceived so far, from the standpoint of the student, both Faculties and the profession.

Introduction

Engineering disciplines have a strong tradition of practical problem-solving. University engineering programs have reflected this in specialized design courses, where the emphasis is on the process, the technical and communication skills involved in the project, and the team work, rather than the demonstration of academic knowledge in a final examination. In New Zealand as in other countries this emphasis has been reinforced in the last two decades as large employers scaled down training programs for young engineers. Government engineering departments were sold off to the private sector and large companies streamlined operations. Universities are expected to prepare students to work in engineering design teams as well as imbue them with academic knowledge and skills.

Over the past few years many educational institutes have addressed such trends by undertaking a variety of approaches. Engineering curricula have been altered to include introductory hands-on design courses at different levels (from first year to final year)[1].

Overview of Engineering Design in the School of Engineering at the UoA

The School of Engineering at the University of Auckland puts a strong emphasis on engineering design education in its undergraduate programs. In the Department of Mechanical Engineering for example this results in a cohesive four-year design course structure. Design has become the focal point of the undergraduate degree program and a common avenue for the application of concepts covered in various engineering and science courses. The design courses are covered by a framework of consistent guidelines and feature a combination of theoretical and practical aspects of design. They maintain a sensible balance between factual, science-based material and open-ended, creative elements. The role of Computer Aided Design (CAD) tools has been carefully considered, and the importance of teamwork and collaborative design has been recognized in the program. In spite of occasional minor problems such as cases of student cheating, excessive workload and ambiguously defined project specifications the design program has been a great success, and many students consider it as the highlight of their curriculum[2].

The Department of Electrical and Computer Engineering in the same School offers three different degrees in Software Engineering (SE), Electrical and Electronic Engineering (EEE), and Computer Systems Engineering (CSE). Whereas the SE program follows the same course structure as the Mechanical Engineering Department, the EEE program enhanced the teaching of their design courses by using a pseudo-professional environment, which is supported by industry partnerships. Experience has shown that this approach can significantly enhance the teaching of engineering design, enriching the experience of the student as well as providing much needed assistance to the University in running such course[3]. The CSE program distinguishes itself again from the other programs by introducing an interdisciplinary environment in a year three computer systems design course. Before the CSE program was introduced CSE staff taught computer systems projects in the Electrical and Electronic Engineering program. Projects were run such as a DC motor control using a digital encoder and FPGA, a Microcontroller and Programmable Logic Controller programming to control a traffic light model, a model elevator, an egg incubator etc.

Important Design teaching aspects

Our reflections in this paper arise from the long history and emphasis on engineering design in the Electrical and Computer Engineering Department at the University of Auckland. Substantial and practical projects are undertaken by students in their final year. The requirements are higher than a mere investigation and often demand considerable investigation, design, construction and testing. As a result the third year requires a substantial preparation in all aspects of engineering. This emphasis was continued in the new Computer Systems Engineering program introduced in 1998 and this paper presents our experience in teaching design in that area over the period 2000-2003.

Design

Design is not unique to Engineering, many other disciplines have developed a tradition of acquiring practical skills and knowledge in a process of continuous involvement over a substantial period of the teaching year, for example studio work in Fine Arts. The importance of

Design is rooted in the nature of Professional Engineering, which is about creating artifacts to solve problems for people:

- Synthesis. This is the key distinguishing feature of Engineering disciplines; the creation of artifacts, both physical and electronic. Many academic disciplines are about analysis, understanding and knowledge. Analysis is also an important foundation in Engineering, because Engineers must understand the problems they solve and the artifacts they create. However, the primary focus is on synthesizing artifacts.

- Problem solving. Engineers primarily solve problems (by creating artifacts).

- Utility. There is a focus on solving problems for people (and little focus on solving a problem for its own sake). Here the emphasis varies across other disciplines; in architecture and graphic design the emphasis is similar to engineering, while in fine arts the emphasis is not oriented to solving problems for people.

Hence the act of Design is the fundamental mode of operation of an engineer. In our teaching we must reflect this; we must teach problem solving and creative design. George Polya explained the four main steps well in his book ``How to solve it.''[4] First one must understand the problem, then devise a solution, then put the solution into practice, and the reflect on the solution (both to evaluate and to reuse parts of it). While the book was about mathematical problem solving it applies well in many areas of Engineering.

This leads to our approach to teaching Design. Students must emerge from our programs with practiced knowledge-based skills in problem analysis, designing solutions, putting solutions into practice, and evaluating solutions. The skill of Engineering Design is not a passive skill. It is not something that can be assessed by an examination of the student's state of knowledge. Nor is Design a manual skill. It is an intellectual creative skill based on deeper knowledge of the discipline. A student may know a great deal, but be relatively useless at solving problem with that knowledge if they do not know how to design. Assessment of Design work must recognize this. Simple tests of knowledge are insufficient. The assessment process must expose the student's abilities in problem analysis, creation of solutions, implementing solutions, and reflection of the work. Our assessments are made therefore by interviews and demonstrations of the work in the laboratory where these skills can be observed and brought out in to the open by oral examination, as well as by examination of written Engineering reports, where the students must express their design process on paper. In addition Engineers usually work in teams so our projects are often undertaken in teams, and the interviews and demonstrations are presented by the Design team, while staff examine group members individually to give a fair assessment. Confidential peer evaluations are used to monitor group dynamics and unequal efforts by students.

The themes in design projects take students through each phase. The problems given to students are not fully analyzed, so that the student can undertake his or her own analysis. The solutions are not fully devised, so that students must create their own solutions (usually within practical constraints). The solutions are not fully implemented even if parts are given, so that students must put their own creations into practice. Projects typically reuse previous student work so that the final reflection stage is reinforced. An important additional matter is that a design project is a kind of learning by case study. Here it is crucial that students have access to all the information and skills needed to make decisions at each point of the case study.

One particular issue in our Computer Systems Engineering program is that designs of computer hardware and software systems are extraordinarily complex. Students are called on to design hardware and software that would have been impossible to build not so many years ago. The level of complexity is perhaps the most significant problem facing professional engineers in these disciplines. It is a problem of systems engineering; putting together a number of complex components to form an overall solution. It is quite difficult to reflect this complexity in the small projects of a typical course. Our approach to this is to give students some projects where for them there is a mass of detail and systems to manage in the one project, plus some careful guidance (but not too much) to take the design in the right direction. The student must be guided to break the problem in to smaller parts, and to modularize the design so that interactions amongst parts are minimized.

So learning Design is very much an experiential process. There is only a little to be gained by giving lectures on what to do. It is a creative process without a mathematical model and without a recipe.

On line learning

The main on line tools we use in teaching design are email, discussion forums and on line documentation. All these tools are combined in a computer based tool called "Cecil"[5], which was developed in the University of Auckland. Email is an excellent way to interact with students about design, in particular because the content of the email can include error messages and design snippets; it is a good medium for expressing problems and solutions. Discussion forums are much better though because all the students are able to see the questions and answers from the rest of the class as well as the lecturers (who has to answer any question only once). In many cases students answer other students questions which saves a lot of time.

On line documentation is an excellent way to present the mass of information needed by designers of digital hardware and software. Usually there is a lot of information available, and if put on line it is searchable, easy to update, and printing costs are reduced. The teaching staffs need only to summarize and guide students as they approach and read the documentation.

Resources

It is helpful to provide students with resources that they are able to use at home as well as in the university laboratories. Small hardware devices can be issued to groups and taken away. Appropriate software can be distributed to students to use at home.

Principles

Some key principles in managing the course include:

- Keeping updated. Both technical and academic staff must invest a considerable effort in keeping up with technology, so that the large effort students make is devoted to technology relevant to expected employment situations.

- Following staff expertise. To maintain the quality of the design and the student experience, it is important to make the most of existing staff expertise, for example bringing our robotics research in to the classroom in simple robotics projects.
- Research oriented. Design projects should be somewhat suggestive of research activities in the department, giving good students a small experience of postgraduate possibilities.
- Increasing freedom. Our design courses run over an entire academic year, as a series of projects. It is important to develop the projects to give an increasing degree of design freedom to students as the year progresses. To begin with more guidance is needed, but as time goes on, the teacher must step aside and encourage the students to take over the guidance, leading to autonomy by part way through the final year of the program.

Interdisciplinary Design aspects

Julainne Sumich, Senior Lecturer in Intermedia and the Time-based Arts at the Elam School of Fine Arts initiated a Science Intermedia Network Environment (SINE), an interdisciplinary digital research hub in 1999. Based on the involvement of the Department of Electrical and Computer Engineering in this group a collaborative teaching project was developed lead by SINE, to encourage (but not force) Engineers and Fine Arts students to work together on design projects. There are a number of benefits:

- Engineers and artistic designers often work together in industry, for example developing products and markets. Inclusion of the Robotics project in their résumé signals that the student is experienced in working collaboratively across disciplines, providing broader opportunities and choices when applying for scholarships, grants, positions of employment.
- There are similar creative processes at work that must be taught, in both areas. By introducing both kinds of student to each other the aim was to develop a greater awareness of design amongst them all. For example, Fine Arts students understand how components in any media through their interaction can assemble into a design greater than the sum of its parts. During the collaboration they gained appreciation of the practical problem-solving Engineering students in Computer Design face in real-world situations: fast turn-around deadlines, parameters of memory storage capacity, constraints on robotic behavior capabilities. In turn, students from Engineering & Computer Systems came to realize that art design is an integrative process that increases the appeal of the product in the public imagination, enhancing its marketable value.
- Taking students out of their familiar environment is focusing, challenging and inspiring, and can help them make rapid leaps in their level of professional thinking, for example the projects boosted Fine Arts students' confidence in integrating electronic aspects into their personal studio practice, and in so doing gained them grades that reflected this extra initiative and research.

In the two robot projects, Vision Sam 2001 and Play Sam: Theatre Robot 2002 Fine Arts students were members of some of the design teams. The interaction was voluntary and students were left to form their own groups, with some encouragement from staff. The groups that met together regularly got to understand one another well and tended to have the more resolved outcomes. Fine Arts students contributed to aspects of robot behavior, such as designing robot sounds and actions. This aspect was part of the project scenario, where the group was expected to develop a marketable robot toy for example. In the Play Sam project, Fine Arts students designed the physical aspects of the robot's stage, as well as contributing to sound and behavior design. Some integrated features of environment and memory with the appearance and behavior of Sam and the sound design of the robot's world.

One example of costume was to maintain the integrity of the robot's structural identity by plastic and electronic additions of eyelids, eyes, and a speaker in the body diaphragm. Introduced to Maori mythology of The Four Winds Nga Hau e Wha by sound artist, Rachel Shearer, this group designed behavior so that "the robot marks out its environment in the performance and paces its boundaries – greeting each corner." The robot sings to itself: variations of burbles, gallops, whistling. Five sound responses e.g. "layered sparse frequencies with reverb" at each "Pillar of Destiny had been designed to evoke some emotional response akin to what the robot is feeling"[6].

Documentaries of the projects in progress and during oral presentations, produced by Fine Arts students were exhibited within the collaborating Faculties, and at public art and science events in Auckland and Wellington. The Four Winds image as shown in Figure 1 is from a documentary "Robot Theatre 2002" by DocFA candidate, Alexandra Monteith.[7]

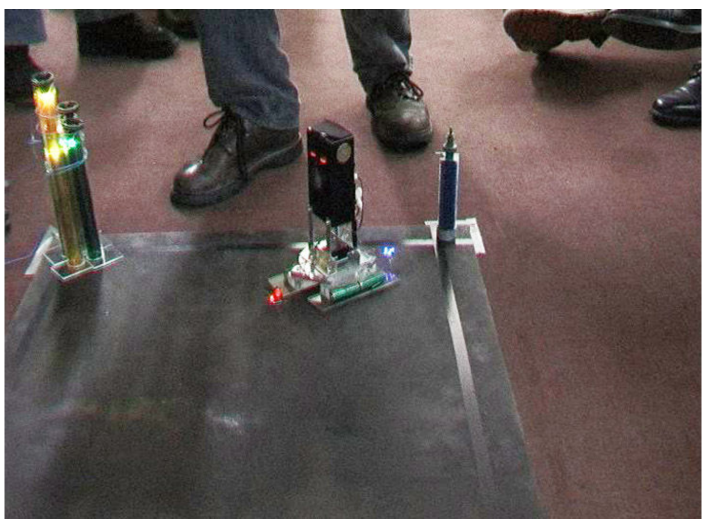

Figure 1: *The Four Winds* presentation, Play Sam Theatre Robot project 2002.

Course structure in the current year 3 design course

The year 3 Design Course at the Department of Electrical and Computer Engineering, Auckland spans a full academic year over two semesters. It is split into three distinct projects each running for eight weeks. The themes of these projects are quite different and aim to address the student leaning objectives mentioned earlier and to increase their enthusiasm in Engineering. A pseudo-professional flavor is forced by presenting these design briefs to the students as design contracts from imaginary companies. The class is partitioned into four person groups. Each group role-acts as a design team in an engineering firm that has been contracted by another company wishing to solve a problem. Each student group appoints a team leader who is responsible for arranging meetings, task division and liaising. All forms of student reporting keep this pseudo-professional flavor in mind and interviews and demonstrations are between the Design Engineers and the Upper Management of this imaginary company.

Each project is split into at least two phases – an investigative phase and the final implementation. The actual names and time duration of these phases differ for each of the three projects. The investigative phase is a 'paper design' phase during which the students explore the various avenues that could achieve the objectives of the design brief. At the conclusion of this phase each group is individually interviewed to assess their design processes and decisions. It also helps identify students or groups not putting in the required effort. During the implementation phase the students physically construct the device as required and finally report their results in a design report, an interview and a demonstration. Each student is also required to maintain a journal. This journal, a hard-backed book, is given to the students by the Department and is considered to be the property of the Department. It can be requested at any time to assess the contribution of the student to the project.

The project deliverables, including the final report, are a group effort and the students are encouraged to work in sub-groups within their own group. Regular group meetings are also encouraged to report and aid the progress of each sub-group. Each member is required to be familiar on all aspects of the project and to be an expert in some aspects. Inter-group communication is strongly discouraged except to tackle broad concepts. Since this course is 100% coursework based and individual grades have to be eventually assigned and recognizing that some students are more competent than others, care has be taken in the assessment. To facilitate this all students are required to complete and submit a confidential Peer Assessment Questionnaire a few days before the final interview. This questionnaire helps ascertain the contributions of each of the four group members. The information in this questionnaire is not directly used to assign a grade to a student but is used to guide the interview to focus on a student or a task and hence validate the peer assessment.

Although this is a design course, a few lectures need to be given to introduce the students to new concepts, technologies, professional conduct and the design process as required for the project. Regular meetings with the whole class also help in tackling common problems like software nuances, instrumentation techniques etc.

Computer Systems Engineering year three design projects during the period 2000-2003 include a wide range of projects such as:

1) DC motor control using a digital encoder and FPGA
2) Walking robots (with vision, play acting and communicating with other robots)
3) Material sensing using line sensors and lasers
4) FPGA based computer game
5) Multi device infrared communication channel

The projects are formulated such that during any one academic year the three projects will give students experience in system design, software development, hardware (analogue and digital) design, instrumentation and debugging techniques. The tools typically used are Matlab, C/C++, Visual Basic, SPICE and MaxPlus. Projects requiring printed circuit board construction used Protel for creating both schematics and artwork.

Course Evaluation

The year three course, *Engineering Design 3 CS*, was surveyed at the end of 2003 by the University of Auckland's Center for Professional Development (CPD). The course itself was taken by 51 students, with 28 completing the evaluation sheet. The students were asked to rate the following statements on a "Strongly agree" to "Strongly disagree" scale. The twelve questions used are listed below:

1. "The course objectives were clearly stated"
2. "Overall, organization of the course was good"
3. "I received helpful feedback on how I was going in this course"
4. "Assessment tasks were effective aids to learning"
5. "The lecturer provided effective handouts and resource materials"
6. "The assessment measured my learning fairly"
7. "The volume of work in this course was appropriate"
8. "I learnt a lot in this course"
9. "Small group work added to my learning"
10. "The course improved my skills in written communication"
11. "The project improved my design skills"
12. "Overall, I was satisfied with the quality of this course"

As discussed earlier, a key educational goal of the course was the teaching of design skills. This can be achieved by understanding the problem first, then devising different solutions, putting these solutions into practice and reflecting on the solutions. The listed survey questions are asked to see if the lecturers provide the right resources so that the students are able to finish the projects on time.

As the survey was administrated by the CPD, it was conducted using the standard forms developed by the CPD staff, hence did not include specific questions to determine how the interdisciplinary nature of the project was received by students in the course. However, the anecdotes observed by the staff during the course and the comments in the "comment" section of the survey forms were generally favorable. The Engineering students who elected to be involved were generally quite positive about the experience. They seemed to appreciate "something a bit different"; the variation and stimulation of working with a different academic culture. There was a portion of the class that wasn't so interested and tended to keep out of the interdisciplinary aspects; we suspect because they saw it as further work in a busy schedule of assignments and study. These students were not negative about the concept though. In a couple of cases the groups continued to do more work after the project was complete. For example some engineers helped some artists exhibit work using the robots they created. The most noticeable concerns resulted from the different disciplinary cultures. While Engineering students are largely required to work to a project specification including deadlines and a fair degree of conformity, Fine Arts students are expected to develop an artistic independence of their own, and do not always conform to engineering schedules. We felt this did not detract from the interdisciplinary work; staff assisted groups to work together and the experience seemed to expand both students' views of team work. The Fine Arts students were seeking technical knowledge applicable to their artistic ideas and in some cases found it in the variation provided by working on the project. In some cases there were not particularly dynamic results, in a few cases new ideas arose and seemed to influence the students overall development in the Fine Arts program.

The survey results are most encouraging and the results appear in *Figure 2*. The following abbreviations are used: SD: Strongly Disagree; D: Disagree; N: Neutral; A: Agree; SA: Strongly Agree; NA: Not Applicable. Survey question one and two is related to the course objectives and overall organization. Over 82% of students felt that the course objectives were clearly stated and the course organization was good. Hence the students thought that the presentation of the design problem was clear. Survey question three to six reflected on the course's ability to help the students to devise different solutions. Over 60% of the class agreed that this was the case. Question seven and eight ask the student's opinion on the relation volume of work versa learning outcome. It is obvious that if the student has to work a lot (53%) that the learning outcome will be high (82%). The industry expects the students to work in design teams as well as be able to communicate to others in oral or written form. Hence question nine to eleven were asked to get the students' feedback. Again, approximately 80% agreed that the course achieved this aim. The last question wants to capture the overall opinion on the course and the student seemed to be happy with the course (78%).

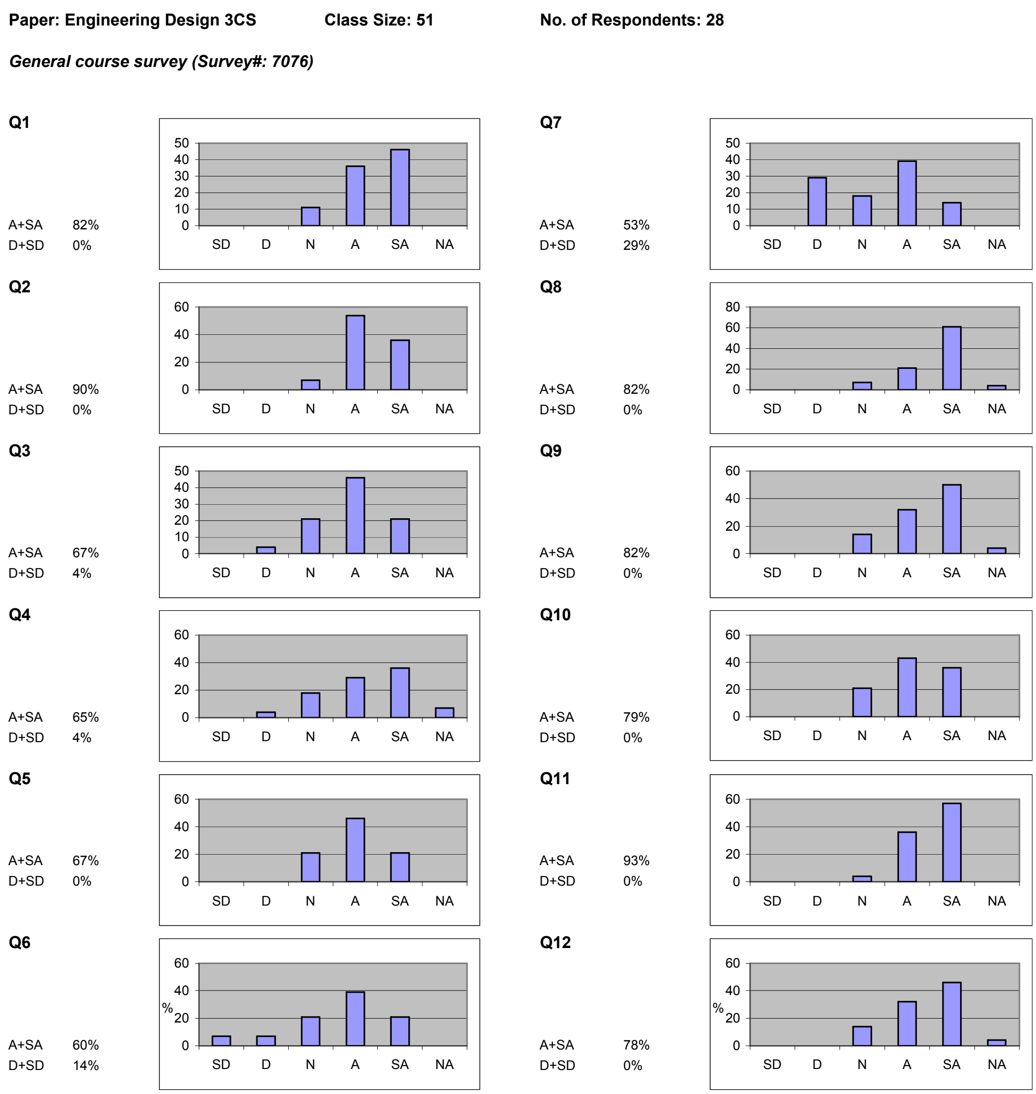

Figure 2: *Engineering Design 3 CS* Student course survey result

Conclusion

In this paper we reported on our recent initiatives in the Department of Electrical and Computer Engineering at the University of Auckland in introducing an interdisciplinary environment in a year three computer systems design course. The course structure and objectives were discussed. Engineering Design represents the emphasis in the engineering profession on solving problems for people by creating artifacts. A strong design theme runs through all years in our Engineering programs, leading to a substantial final year project. In design projects students practice knowledge based skills. An interdisciplinary aspect was introduced to Computer Systems Engineering design with Fine Arts students. Course evaluations were very positive.

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