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Research-Based Education in Computer Science at the ANU: Challenges and Opportunities

Peter Strazdins

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Peter Strazdins

August 21, 2007

Abstract

This project examines *research-based education*, which includes *research-led education*, in the discipline of computer science at the Australian National University. It traces the University's position on the issue over recent years, and it explores and evaluates current practices of research-based education. Of particular interest is the newly-introduced Bachelor of Computer Science program, which is found to have many issues in common with the University's flagship research-oriented degree, the Bachelor in Philosophy (PhB) program. From the analysis of data from semi-structured interviews with both BCS students and academics either involved in the BCS and/or whose teaching practices relate to research-based education, this project explores the range of staff and student attitudes and experiences in this area. It then identifies challenges and opportunities in creating an expanded and more coherent use of research-based education through the computer science curriculum.

This project makes the following main conclusions. Firstly, that the range of staff and student attitudes and experiences concur with what is found in recent literature. Secondly, there are several important lessons for the BCS program and research-based education in general that can be gleaned from the PhB experience. Thirdly, that there are in fact already a large range of practices of research-based education in computer science (but there has previously been little overall awareness of this). Finally, that if applied judiciously, the potential benefits of research-based education are considerable, in terms of higher quality pedagogical outcomes, enhanced student and academic experience and a positive future impact in computing-related industry.

Contents

1 Introduction

In 2004, the Australian National University began a strategic shift in its coursework teaching programs, with the goal of orienting it towards what is termed *research-led education* (RLE) [15, 16]. In this context, the term means the inclusion into the curriculum of the (advanced) topics where the institution is currently conducting research. A broadening of this concept is *research-based education* (RBE), which aims to produce graduates with research skills and experience, as well as being knowledgeable in the frontiers of a discipline, where research is being conducted.

This project aims to address opportunities and challenges for this shift in the discipline of computer science. This will be done in the context of undergraduate and postgraduate coursework degrees currently run by the Department of Computer Science (DCS) in the College of Engineering and Computer Science (CECS).

This document is organized as follows. Section 2 outlines this project's objectives, with Section 3 giving the relevant background, with respect to the literature and to the context within ANU. Section 4 gives a selection of examples of current practices of RBE in computer science teaching within CECS. An analysis of data on the views, perceptions and visions of RBE gathered from interviews is presented in Sections 5 (student perspectives) and 6 (academics). Overall trends and conclusions are given in Section 7.

2 Objectives of this Project

The objectives of this project are as follows:

1. to compile a selection of examples of current practice in research-based education in computer science, in order to identify a spectrum of opportunities.

2. to perform a limited evaluation of these examples, from both the students' and teachers' perspectives.

3. to survey teacher and student attitudes on research-based education, in order to identify possible obstacles and new possibilities for research-based education.

4. to suggest opportunities for expanding research-based education in existing computer science degrees.

3 Research-Based Education: Background

This section reviews some key literature on the subject, and outlines fundamental principles and elements of research-based education. It also looks at the issue in the context of research-oriented undergraduate degrees currently at the Australian National University.

3.1 Key Ideas and Findings from the Literature

There are various ways in which research may be introduced into university teaching [2]:

1. the students learn about research findings, with the curriculum is dominated by staff research interests and is taught by a transmission-based mode.

2. the students learn about research processes, how knowledge gets created, and the 'mind-set' of a researcher.

3. the students learn by acting as researchers, learning the associated skills of research, with the curriculum dominated by inquiry- based activities.

These are generally termed *research-led*, *research-oriented* and *research-based* approaches respectively, but there is little consistency in the use of this terminology [2]. In the earlier ANU proposals [15], the term *research-led* was used in a way that was largely consistent with the first approach. However, in this and later documents [16], there is an emphasis on scholarly community and inquiry-based learning, including elements of all approaches. For want of a better term, we use the term *research-based education* in this document to mean a combination of these approaches.

A precept, attributed to John Dewey, advocating the second and third of these approaches, is that "*learning is based on discovery by mentoring, rather than on the transmission of knowledge*" [8]. The same report advocates a model where "*undergraduates ... become an active part of the audience for research*". It recommends that students engage in research in as many courses as possible from the first year, learn how to communicate research results, take inquiry-based courses with collaborative projects, are given a mentor, join a research team, participate at seminars (including giving their own), and take internships.

How such a vision can be achieved is outlined in [4, Ch. 4], with a framework linking student learning through staff research. This includes what is mentioned above and students "participating in research conducted by their lecturers" and "learning and being assessed by methods resembling research procedures".

The view cited in [8] highly advocates research-based education in research-intensive universities. Other literature, summarized in [2], notes there is a conflict between such a model and vocational interests, and students who are extrinsically (e.g. vocationally) oriented may not respond well to such approaches. Furthermore, studies show many academics in the hard disciplines believe that students need to acquire sufficient basic knowledge before they can contribute to research.

The relationship between teaching and research activities at universities (called the *teaching-research nexus*) may act in both directions. For example, [8] espouses the idea of a scholar-teacher: whose teaching flows through what they learn in their research, and whose research is also affected by their teaching (e.g. through interactions with students, directly or indirectly, one's own ideas may be enhanced). The relationship is explored more systematically in [11], finding that five qualitatively different experiences can be found in academics, ranging from being "incompatible activities" to "teaching as a means of transitting research knowledge" to that they "have a symbiotic relationship in a learning community".

Studies on the student benefits of being exposed to research-intensive lecturers (who incorporated some aspects of research-led education in their courses) included "enhanced knowledge currency, credibility, competence in supervision and enthusiasm/motivation" [6]. Also consistent were the perceived drawbacks of reduced availability and effort put into teaching by research-intensive staff and curriculum distortion, but the number of positive of comments dominated the negative. These findings were consistent with undergraduates and postgraduate groups. A study of research-intensive undergraduate summer internships in the sciences showed the students had overwhelmingly positive experiences, with the main benefits being cited as "personal/professional gains", "thinking and working like a scientist" and "gains in various skills" (that are broadly applicable) [12]. The collegiate working relationship with the mentors was cited as an important factor in this. However, there seem to be few evaluations of student experience between a research-based and traditional education throughout an undergraduate degree.

Related concepts are *inquiry-based learning* and *problem-based learning* (PBL) [2], where major learning activities are driven by the process of inquiry and the solution of a given problem.

3.2 Research-based Education and ANU's Vision

As mentioned previously, over 2004 and 2005, the ANU saw an opportunity to distinguish itself by offering 'education informed by recent research" through a range of "research-led degree programs based on interactive enquiry", based on its position as being Australia's most research-intensive university [16]. Critical enquiry, deep approaches to learning, reflective practice and research experience early in the degree were given as key elements of these degrees, ranging undergraduate to postgraduate programs.

Following on from this, a working group was set up to steer directions for ANU education through to 2009 [17], foreshadowing that "*ANU over the next five years ... [will] turn the rhetoric of research-based education into reality for all students*". The group proposed that each College identify the relationship between teaching and research in existing and new programs and courses. It also proposed students be integrated into a research community, with a personal tutor for all first year students.

In 2006, there seemed to be a change in terminology in this vision, and possibly a softening or broadening of it as well. The terms *discovery* and *curiosity* seemed to displace the terms *research* and *inquiry*: e.g. "*ANU students learn through discovery: of knowledge, skills, and ways of thinking that are new to them*" and "*ANU academic staff transmit new knowledge and scholarly insights in a curiosity-led learning environment"* [18]. *Flexibility*, in the sense of allowing students to pursue their own interests, was also emphasized.

The position became more clear in the following year, with the statement that "the quality of education at ANU is measured by analysing indicators including . . . research-led education", as well as "flexibility, combination and progression" [19, p8]. Subsequently, the former is termed as "research-led, discovery-based education" with a recommendation that innovation be used to "foster this discovery-based learning, maximally engaging students and challenging them to question the fundamentals of their discipline" [19, p70]. This seems to encompass the broad definition of *research-based education* used in this paper, and indeed the term itself is used: "survey findings [were] that students prize the research-based education they received" [19, p70].

3.3 Research-Oriented Undergraduate Degrees at the ANU

The PhB (Science) program is the flagship research-led undergraduate degree program at ANU [16]. It is a "research-focused" Honours program requiring a UAI of 99 for entry. It has also a counterpart in the Arts. It requires six advanced study courses (ASCs) over the first three years, which often take the form of research projects with an academic instructor/supervisor. Each student also has a 'mentor' throughout their program.

An evaluation of the PhB (Science) program was recently carried out by academics closely involved with the program [3]. The authors submitted this report as part of the requirements of the Graduate Certificate of Higher Education (College-based Program), which they were enrolled in over that year. The assessment focussed on student and ASC instructor experiences of the ASCs, and involved surveying as many of these as feasible. The relevant results of the report are summarized below.

The report found that first year students chose the PhB primarily because of the challenge and flexibility of the program, whereas older students (already exposed to a research environment) primarily cited the opportunities for research. The majority of students were neutral on the benefits from their mentor, with many forming closer relationships with their ASC instructor. While again there are exceptions, most had had a positive relationship with the instructor. The strongest perceived benefits of the ASCs were the learning of generic research skills and the resulting personal development (e.g. broadening of perspective) from being exposed to research. Overall, there was a perception that the PhB was fulfilling its aims, but workloads was generally perceived to be high and more "enthusiastic and proactive academics" need to be involved in the ASCs, there needs to be more homogeneity in ASC standards, and the social aspects of the PhB need improvement.

From the staff perspective, it turns out that there were only a few instructors that had supervised more than three ASC projects, and that few mentors have ever been instructors. Views of the aims of the PhB concurred with the stated aims of the program; however there was a division of views on the aims of the ASC between "research preparation" and "research exposure". There were indications that many of the instructors did not "envisage any kind of educational outcome". There is evidence also that "ASC operation and assessment do not reflect the focus on generic research skills", and that marks may be allocated in an ad hoc fashion (with possibly unrealistic expectations).

The report concludes with several recommendations to improve the PhB, including mentor training, improved quality control (including 'information packs', which are then tailored to each project with clear expectations and learning outcomes being defined), and providing assistance with generic research-related skills.

The Bachelor of Computer Science is a "research-oriented" degree of a similar nature, but specializing in computer science. It is discussed in detail in Section 4.1.

4 Current Examples of Research-based Education in Computer Science

In this section, a selection of examples of current practices in research-based education are described. These are not intended to be exhaustive, rather to be indicative of the spectrum of existing approaches.

4.1 Bachelor of Computer Science: Research-led Foundations of Computing

The Bachelor of Computer Science was introduced in 2006 as a research-oriented degree for highly talented students. Research-led education figures in the Data Structures and Algorithms subjects COMP1130 and COMP1140, where foundational aspects of the computer science curriculum are delivered via "problem seminars which will be seeded by an academic who will introduce a problem, typically associated with his/her research area".

The COMP1130 web page and the COMP1140 web page give more detail of their activities.

The only other courses unique to the BCS are the 6 unit courses COMP3130 Group Project and COMP3006 Research Project. Apart from these, no other project work is prescribed until the Honours year.

4.2 Research-led Education in Advanced Courses

At the 3000-level, the courses COMP3320 High Performance Scientific Computation and COMP3620 Artificial Intelligence are known to introduce topics of current research by the teaching academics. The course COMP6444 Software Design for eScience is based on the lecturer's own research interests (in this case *design patterns*), as is COMP3110 (mentioned below).

New opportunities emerged for COMP3320 in 2006 with state-of-the-art computing platforms being specifically made available to the students. Students had the opportunity to undertake a project-based group assignment to implement the Message Passing Interface (MPI) middleware on cluster computer. This project spanned most of the semester. The mainstream assignment (molecular dynamics) was also seen as problem-based. However, elements of lectures touched upon cutting-edge research (e.g. interval arithmetic, cache-oblivious algorithms, Fast Multipole Methods).

In COMP3620, current research is also introduced in some lectures. Similarly, the guest lectures in COMP3300 Operating Systems which involved researchers from industry can also be seen of this nature.

COMP3110 Software Analysis and Design incorporates a problem-based approach with its assignments, in that students are given real-world examples of systems to analyse, and is open-ended with students having to use their understanding to define the task. It incorporates state-of-the-art foundations and methods in research (as practised by the teachers) in the form of *executable specifications*.

At the 4000-level, there are several courses offered on a year-to-year that can be considered research-led. One such course is Programming Language Implementation. Lectures are based on current research findings, and the students are given papers to review. Furthermore class projects are based on current research problems: the aim is to "generate a contagious amount of enthusiasm".

At the 6000-level, the course COMP6390 Human-Computer Interface can also be considered research-based. By nature, this course has the advantage that cutting-edge-research is closer to the level of the student's understanding. Course materials are based on key older research papers, giving enough background for students to then study recent research papers. Students are taught research methods and the experimentation undertaken by students also mirrors that done in research.

Real-world experiences, some research-oriented, are also brought into the syllabus of 4000/ 6000/ 8000 -level Software Engineering (SE) courses. As in COMP3110, some research interests, such as aspect-oriented modelling/thinking, are also incorporated.

4.3 Teaching the Process of Discovery in an Algorithms Course

One of the highest-level research skills is that of *discovery* in the context of mathematical theorems and key computational algorithms. This is however rarely or not at all taught, nor even discussed in original papers; the readers are merely presented with the finished product.

In 2005, in the advanced course COMP3600 Algorithms, the lecturer's personal process of *discovery* was discussed in terms of an algorithm and associated proof relating to the Max-Profit

Scheduling Problem (lecture 20). This included the extensive use of examples to gain a better understanding of the problem; the mistakes made / and dead-ends followed, and how these lead to the next step; and the use of techniques in which to check a proposed solution for its validity.

4.4 Research Project Courses

Research projects can be undertaken at the 3000-level via the courses COMP3700 Topics in Software Engineering I, COMP3710 Topics in Computer Science, COMP3750 Project Work in Computer Systems, COMP3760 Project Work in Information Systems and COMP3006 Computer Science Research Project. COMP3006 is the only such course for the Bachelor of Computing. To date, enrolments in these courses have been scant.

At the 4000/6000-level, research project courses are available in the Computer Science (Honours), Bachelor of Software Engineering, Bachelor of Computer Science, Masters of Information Technology (MIT) programs. These are generally from 18 to 24 points in size.

Implementation-based projects are also available in the most of the above areas (particularly in the MIT, and in its successor the Masters of Computing); these may incorporate some elements of research as well, and also involve some research-based skills (see Section 4.5)

4.5 Teaching Research Methodology at the Honours and Masters Levels

The course COMP4200 Milestone Papers in Computing teaches research-oriented skills in terms of literature searching, critical evaluation of key research, and presentation.

In 2006, a series of short seminars on generic research skills, such as giving presentations, were given by a guest speaker from ANU's Academic Skills and Learning Centre.

The MIT (eScience) project courses have exposed students to these and other research skills in the context of a practical project, with their teaching being left largely in an ad hoc basis to the supervisor and student. In 2006, an initiative was taken to more systematically teach these skills by forming a Community of Practice (CoP) [20, 7] including the students and the co-ordinator, focussed on a series of study meetings.

Here, students were able to benefit from each other's and the facilitator's expertise and a strong group identity was forged. The action research method [5, Ch. 2] not only improved teaching practice within and between the running of the course, but had the side-effect of increasing student ownership. The students learned generic research skills in the context of their own and other students' projects. This had strong benefits in terms of motivation and experiential learning [13, Ch. 3]: an inherent advantage of the CoP approach.

The CoP was similarly run in semester 1, 2007.

4.6 Problem-Based Programming in First Year

Normally, first year programing assignments are tightly specified, allowing for limited creativity and initiative amongst the students. In 2005 and 2006, in the course COMP1110 Foundations of Software Engineering, there was a highly successful initiative for students to formulate and implement their own practical work in small groups. This formed an overall project which was integrated into the assignments and laboratory work over the semester, and reinforced many concepts in the lectures.

While this should be regarded as an example of problem-based rather than research-based learning, it is an example of how such an approach can be incorporated in courses where there seems to be few opportunities otherwise for it.

4.7 Teaching Experimentation in Computer Systems (2000/3000 level)

Experimentation in the form of computer performance evaluation is an important research skill in computer systems research. This has been taught at the 3000-level in the course COMP3320 High Performance Scientific Computation (and its predecessors).

This skill was brought down to the 2000-level in 2006 in the course COMP2300 Introduction to Computer Systems. Here, in the second part to Assignment 2, the memory hierarchy of a modern computer system was studied. As well as traditional, calculation-style exercises, students were given a sophisticated test program which could measure memory hierarchy performance in a number of ways. They were given a number of experiments to perform using this test program, and had to infer properties of the memory hierarchy based on the results of their experiments. There was scope for students to propose their own experiments and gain bonus marks. There was also a place for students to write comments on their experience of completing this part. This work was an extension of research recorded previously in a conference paper [14] co-authored by the lecturer.

4.7.1 Evaluation

An evaluation of the research-based memory hierarchy assignment above is given here. It should be noted that this 'assignment' was actually the second and smaller part of a submission, whose first part was a substantial programming exercise.

98 students (out of 120) attempted this part of the assignment with an average mark of 10.6 out of 20. This can be compared with an overall average assignment mark for the course of 65%. The low student performance can be attributed to the following factors.

- It was huge challenge for even the strong students, in that they needed to think deeper and in a different way about computers than before. About 1/4 of the students excelled and enjoyed the experience.
- Only the stronger and more organized students were excited. The other students generally made a half-hearted attempt at the last moment. Indeed, most were still struggling with the first part of the assignment by the submission date.
- Many of the students felt lost, and found the experience frustrating. The main opportunities for support were at the tutorials, but this opportunity was largely lost, for reasons mentioned above. Some motivating background was given at a lecture, but there was no attempt to teach how similar problems could be worked through.

The above observations came from reading a sample of a third of the experience survey question in the assignment, plus the author's observations as a lecturer and tutor.

From the teacher's point of view, it was a lot of work. This was mainly in setting up the infrastructure so (naive) students could perform the experiments and get reliable results, and in working out and providing the background knowledge needed.

It was concluded that more work, support and care are required if this kind of teaching can be made successful to a student body of largely non-elite students at the early 2000-level.

In 2007, this was followed up with a similar assignment. With lessons from the previous experience in mind, there was some tutorial support given to treating the underlying concepts, and the assignment was submitted on its own. This resulted in improving the submission rate to 90% and the average mark to 20.0 out of 32, indicating the above problems can be to an extent addressed [1].

5 BCS Students' Perceptions of Research-based Education

This section details the experiences and perception of four first year BCS students interviewed in 2006. As there were 10 students enrolled at this time, this is not an exhaustive number, but should be sufficient to indicate the range of perceptions and experiences. It should be noted that all students were invited, but only these four consented to participate.

Four such interviews were conducted over August 2006; the interviews were semi-structured, with questions covering their experiences of and approaches to study, and their experiences of the BCS and Research-Based Education. Appendix B lists the interview plan.

5.1 Approaches to Learning

The students all used a deep approach [9, 10, 1] in their learning style, expressed satisfaction at being able to solve complex problems, and made extensive use of reading and seeking relevant references in order to improve their understanding.

Together with their high degree of scholastic aptitude, all of these factors combine to give a near-ideal profile for undertaking research-based education at the the undergraduate level.

However, two of the four interviewees, with evidently less computing experience, indicated that they liked and needed structure in their learning, and disliked "*being thrown in the deep end*". For such students, careful support in terms of clear expectation of learning objectives, systematic teaching of generic research skills, and education-oriented supervision is needed, as is recommend for the PhB [3] (see Section 3.3).

5.2 Perceptions and Experiences in the BCS

When asked for reasons given for choosing the BCS at ANU, all four students indicated that ANU was their institution of preference, and they favored the BCS over other Computing and Science degrees. Reasons for the latter include the higher UAI/eliteness of the degree (2), the BSEng seeming less interesting (2), and the BCS promising to be "faster, more interesting".

When asked on what the BCS being a 'research-oriented program' meant to them at this stage, the responses included an advertising term (2), the degree would offer the opportunity to be a research assistant, (1) and the degree would involve learning about research methods (1). It seemed that only one found this label in itself attractive at the time. At the time of the interviews, they tended to perceive it as meaning preparation for further research (2), and/or doing some research activities in the coursework (2).

[1] It should be noted that there were still a number of 'half-hearted' submissions which pulled down the average mark; these in part can be attributed to the submission date being late in the semester and the overall weighting of the assignment being relatively small.

When asked what they hoped to get out of the BCS, three responded it was to get a deeper (sometimes more theoretical) understanding of computer science, with one expressing interest in doing research in the future, and another undecided on this.

In terms of their relationship with their mentor, only one student was highly positive, citing the mentor's enthusiasm for their research as the main reason. One student said their mentor gave occasional useful feedback, with the other two describing their relationship as irrelevant.

When asked about their relationship with other BCS students, it appeared that two groups had emerged in the student body: one that with those that "knows everything" and one with those that are "unsure". Within these, all had some useful interactions, mainly in discussing work (but little helping with assignments), and this largely occurred during contact hours. There was little indication of purely social interactions. There were suggestions that cohesion could be made stronger by more group exercises in tutorials (as is done in COMP2600) or by group assignments.

There were few indications of significant social interactions with other computing students.

5.3 Attitudes and Experiences of Research-based Education

The were various responses to what the term *research-based education* meant to the students. It included getting students to "research things for themselves" (2), "researchers giving lectures" (1), and focussing learning on current research topics (1).

When asked what examples of what could be termed research-based education they had encountered so far (they had all encountered by this stage the courses COMP1130/40 and COMP2300 by this stage, see Sections 4.1 and 4.7), three cited the COMP2300 memory hierarchy assignment as the main example, but all mentioned COMP1130/40 to a small extent fitted such a criterion.

Comments on the COMP2300 memory hierarchy assignment include it was much more interesting than a standard assignment (that is "on a well-trodden path"), and very challenging in that a deeper understanding had to be built up in order to answer the problems. Their approach to learning in such a situation was different in that they had to actively seek way of building their understanding on the topic first. One of the interviewees said such an exercise would have been improved if provided with more resources; this was seconded by the student who did not cite this as an example, who also said it was important to review the solution after the assignment was handed in. This student also echoed the comment that research-based education is potentially more engaging and satisfying (but only if you could arrive at a satisfactory solution).

COMP1130/40 was perceived to involve research-based education less central ways, e.g. in some of the programming exercises (2), or in comments by some of the guest lecturers (1). It was perceived that theory dominated these courses, with not enough time to do many things of a research nature.

In terms of the rest of their degree, all foresaw the project courses (3rd year and Honours) as involving research-based education, and seemed excited at the prospect. However, one qualified this, stating that how it was done (in terms of resources and help) was important. Another said that it needs to be curiosity-driven, and the topic must be solvable and relevant. Only one student foresaw research being introduced into (lectures of) the advanced coursework subjects.

When asked if they wished more research-based education introduced into their degree, one stated that COMP1130/40 could incorporate it more, and other courses could do so in their assignments. Two preferred the PhB model where project work was available in the first and second years.

In terms of the advantages of research-based education in later life, preparation for further research (1), gives a broader perspective and deeper understanding (2), and gives a valuable mind-set even for industry career (1 - definite, 1 - maybe). Another student was neutral on this last point.

6 Analysis of Academics' Perceptions of Research-based Education

This section details responses from the interviews of eight Computer Science academics from the College. Its structure followed that of the interview plan given in Appendix C, which was broadly similar to that used for the students, concentrating on the experiences and perceptions of RBE and the BCS. These academics were approached because of their potential interest in the topic (and particularly those involved in the courses mentioned in Section 4, and is not intended to be a representative sample. Nonetheless, it is hoped that the data combined will give a range of views and insights into the topic.

Four semi-structured interviews were carried out in November 2006, and a further four in early 2007. The participants were given a draft of this report before its publication, to approve or otherwise text relating to their contributions.

6.1 Understanding of the Term RLE/RBE

All academics shared the same view of the definition of the research-led education (see Section 3.1), but there were differences in the broadness of how it might be applied, which is reflected in their understanding of the term research-based education. Only a few seemed to see the teaching of research skills as an important part of research-based education.

Some broader and interesting perspectives emerged:

- "research means generating new knowledge, so research-led education means teaching students how to generate new knowledge."
- "research-led education should include research that is of practical use to practising engineers in the next 0 – 5 years."
- "for CS, its a different situation – the research introduced should be of use to (future) practising scientists. i.e. the research introduced to education must be appropriate to the student groups – engineers or scientists."

About half the academics differentiated problem-based learning from research-based education, whereas the others saw the former as an inclusion, with a continuum existing between the two.

Three academics were supportive of the problem-based approach where possible / appropriate in the design and carrying out of assignments. The intention would be to increase student motivation and engagement, encourage students to think for themselves more, and to exercise skills in project scoping.

6.2 Evaluation of Own RBE Practices

This section gives some of the interviewee's self-evaluations of their research-based education practices, presenting a mixed picture.

- Section 4.7.1 already gives a self-evaluation by the author of the teaching of research skills in the course COMP2300 *Introduction to Computer Systems*. The course also contained some advanced research-motivated topics (c.f. Section 4.2); one interviewee noted that the performance in the exam in these topics was quite poor, indicating they are too far above the level of the average student.

- The Human-Computer Interface (HCI) course (Section 4.2) received very good reviews from students. It was evident that it improved quality of HCI aspects of subsequently taken SE projects by the same students.

- The MIT implementation projects (Section 4.4 were deemed generally not cost-effective in producing research. The reasons cited were the timescale is too short (1 semester) and the student quality is insufficient.

- In the course COMP3110 (Section 4.2), the teaching of executable specifications drew a mixed responses from the students. Some found it relevant, others disagreed.

- In COMP1130/40 (Section 4.1), the exposure of the students to a number of researchers who relate material to their research interests was thought to have been reasonably successful.

- All those involved with courses using PBL (Sections 4.6 and 4.2) reported that this approach worked well generally.

6.3 Awareness of Others' Current Practices

There was very little awareness of other staffs' practices in research-based education, or where it might be practised otherwise in the College. Research-led education in the advanced courses (Section 4.2) were the only examples cited. Conferring with the findings of Section 4, this indicates a general lack of awareness of others' teaching practices.

6.4 Background Required for Meaningful Participation in Research

Most interviewees said that it was dependent on the sub-field, i.e. the closer the frontiers are to the students' level (e.g. HCI), the easier. On the other hand, for a sub-field like computer systems, it was felt that a large number of skills was required.

For Software Engineering, it was felt that generally students needed to be at the 4th year level, as only there do they have sufficient maturity.

There were however opposing views: one interviewee felt a clearly-defined task could be tackled in 1st or 2nd year. Another stated that "clear thinking is the dominant [skill] - the need for specifics is often over-rated".

6.5 On the Teaching-Research Nexus

The overall view on this is that these two activities are not mutually exclusive, but generally teaching activities are seen as detracting from research. There were few specific examples on how research relates to teaching; one interviewee stated that "it can inform teaching, but problem that it is too narrow'.'

Ways in which teaching can relate to research included research into educational methods, that teaching can improve your own understanding and forces you to keep current, that a researcher should be able to teach (communicate) their research, and that it is a means of cultivating of potential researchers:

> Why else would they [students as potential researchers] come to a research-intensive university?

One interviewee stated a stronger example, in that teaching had motivated him moving into to new areas of research.

6.6 Perceptions of the BCS

As for the BCS students themselves (Section 5.2), there were a range of views in this issue.

To most, the term "research-oriented program" meant training for (a career in) research. To one, it suggested a "set up to feed RSISE/NICTA". To a few, it suggested more about concepts, less about vocation.

When asked what they thought this term suggested to others, one commented that the traditional research stereotype does not fit well with CS - it may be hard to market so as to inspire excitement. Negative views included 'ivory tower' / elitism, and it may be off-putting to potential employees or vocationally-oriented students. Another felt it it may not mean too much to high school students in any case. One the positive side, one thought it could build on the strong reputation of ANU, and three thought it might draw good students.

When asked what the goals of the BCS were, a widespread view was to gain good PhD students thereby. One commented that it was important to give a good grounding in the basics and not to specialize too early.

When asked on whether PhB-style projects should be introduced, about half thought having these all the way through were a good idea, but others were more cautionary, suggesting they should only introduced in second year or it should be taken on a case-by-case basis, depending on the student's background. It was generally felt that the BCS needed a stronger orientation on research than has the status quo; possibly mentoring, or attaching a student to a research group.

There was general opposition to the idea that the emphasis on RBE should be extended to other undergraduate degree programs, the main reason cited being that other students may miss out on basics, and there was an increased danger of students dropping-out. One commented that the uniqueness of BCS may be lost thereby. But another commented that the BCS will bring RBE into the rest of curriculum by osmosis.

6.7 Strengths, Weaknesses, Opportunities and Threats

Strengths: The main strengths of Research-Based Education were perceived to be on the student side. A prevalent view was that it could give a more interesting and unique experience for the students, by relating knowledge to real-world problems. Many felt it permitted a stronger focus on concepts, and forms thinkers that can solve problems independently (rather than 'tradesmen': "we need to be cautious about too vocationally-based education"). Similar with the views that it could give a broader way of thinking, it could produce students with a more critical of conventional wisdom, who are able to appreciate "there is a lot going on they don't know about" and who could understand how new knowledge is acquired. This was considered especially important in these days of changing careers and technology (lifelong learning).

There were 2 expressions that such students would be able to go on to raise the standard in industry. It could play a role in professional education: "students need to see that the discipline is evolving, that research is driving it" and that "they would be more willing to consult with the University in the future".

In terms of teaching, several thought it would allow enthusiasm to be injected into it, and it could improve the quality of teaching. One expressed that it can be more satisfying for the teacher. In terms of research output, two stated it would recruit more research students, and one thought research output could be increased by project work by undergraduates at a suitable level (e.g. in the BCS).

Weaknesses: These were similarly concentrated on the students' perspective. It was felt it is not for everyone, especially at lower undergraduate level, where they don't have the necessary background. We may may lose students without sufficient interest/ability, and such students are not suitable in any case for research activities. From the pedagogical viewpoint, it might impart a possible loss of relevance, as our research interests are very specialised, and (in the case of research-based assignments) the learning objectives might be unclear.

From the teacher'sviewpoint, again focusing on the case of research-based assignments, it is hard / time-consuming to set up and to get students working in groups. In general it would imply a bigger workload, as our undergraduate student numbers are too high. On extending RBE to project work, it was felt that it often has little reward for the supervisor if the project time is too short or the students are sub-standard.

Opportunities: Then main view is that RBE could give ANU a niche: "ANU is a research-intensive university: it is what we should be doing". One expressed the view that it may work if we tried to do this from the beginning, but could problematic if not everyone follows suit; another felt that we need to present a range of opportunities to inspire our students. One commented that it could link in NICTA/RSISE and move CECS forward. The general consensus was that it has a greater place at the upper level of undergraduate study.

Threats: Views cited included possible antipathy from academics who see education as vocational, or feel threatened by the focus on research. Another view was that our high teaching loads may preclude the extra effort needed for RBE; and this is exacerbated by the small number of staff and too many degree programs. A possible result would be that the research school / NICTA may end up getting the good research students, unless possibly we can get the students to believe that the research programs in DCS are just as exciting.

In terms of the university, it was felt that ANU might be seen just as for top-end research, not for industry jobs, and that (professional) accreditation requirements of degrees might get in the way.

6.8 Visions for a Way Forward

On the question *should RBE be expanded in CS curriculum?*, the responses were overall positive, but the following preconditions were outlined:

- the students must be of sufficient quality.
- the nature of the course is also relevant.
- the teachers must be active researchers. Also, the relevant research programs must be attractive and of high quality.
- good rapport must be maintained with undergraduate students if we wish to retain them for further research.

In terms of how to go about this, the following were suggested:

- hold an audit of curriculum design with respect to RBE. “Courses without synergy with research can be axed – unless they have strong professional requirements”.
- introduce RBE lighter in the lower undergraduate level, and increase it gradually. However, even in the introductory courses, we could incorporate inquiry/problem based approaches, and teach some research skills.
- “people should rethink their courses (for RLE) and set assignments that have properties (give ideas of frontiers of field, show how state-of-the-art lacks, work back to a problem that can be solved today, etc)”.

  “How RLE could work in the context of an AI course. We could give a vision of 2050 with a World Cup class robot soccer team. Then we show them where the current state-of-the-art differs. And then work back to a problem that can be tackled today, e.g. planning using current soccer robot prototypes, and get them to work on this.”

  An expanded version of this vision is given in Appendix A.
- a compulsory research project could be introduced as part of BSEng.
- introduce a Masters-level Synthesis Project (as is done at the University of Massachussets), where a student works on a research topic which spans two research groups in the College. The goals would be to give broader perspective on the research field for students, for increased interaction between research groups, and the production of more publications.
- the new course COMP8400 Algorithms for Data Mining presented good opportunities for introducing RBE,

7 Conclusions

Research-based education continues to be an important indicator of both teaching quality and the uniqueness of approach of the Australian National University. This is natural due to its research-intensive nature.

In this project, we have found that the range of staff and student attitudes and experiences on RBE concur with what is found in the technical disciplines in other universities, as is recorded in recent literature. That is, in the worst case, teaching may be seen as detracting from research and a strong research focus may result in a teacher putting little effort into teaching. However, in the best case, a teacher who is an active researcher may impart greater enthusiasm, relevance and depth in student learning, and that project work supervised by an active researcher can be highly rewarding experience, even in the long term.

There are also several important lessons for the BCS program and research-based education in general that can be gleaned from the PhB experience. Firstly, that students are not initially attracted to the degree for its research orientation in any strong way, but may come to value this aspect highly in later years. Secondly, the effectiveness of mentoring needs be evaluated more closely, there needs to be better integration of mentors and project course supervisors, and social aspects of the course need improvement. Thirdly, that there are variations in the learning approaches of BCS students, with one cohort being likely to cope with "problem-seminar" approach in the first year and largely independent project work later, and another needing a more systematic and structured style of teaching. Overall however, as a group, they are near-ideal students to flourish in research-based education. Finally, there is (qualified) support from both the students and academics for earlier project work. However, the lessons of the ACSs should be kept in mind with the need for the setting of clear expectations, the notion that pedagogical outcomes are important and that these include generic research-related skills (which is often overlooked), and the setting and adherence to clear standards in supervision and assessment. With the recent explosion of the number of CS project courses (including that of the BCS), this is particularly important. A followup and more broadly focussed evaluation of the BCS degree is now due.

This project has found that there are in fact a large range of practices of research-based education in computer science already in use, but there has previously been little overall awareness of them. They include using problem-based approaches and teaching research skills at the lower to mid undergraduate level. Lessons can be learned from each others' experiences provided communication between academics is improved.

It has also found that the following conditions are needed for successful research-based education in computer science. The students' inherent quality and to an extent maturity must be sufficient. In terms of teaching, an integrated approach is important, with a symbiosis of good quality teaching and research practices. For project courses, size of the project needs to be sufficiently large (e.g. at least 12 units). This suggests the third year project work for the BCS students, which start in 2008, could be designed to span several project courses (COMP3130, COMP3006 and possibly COMP3750/60).

For a more extensive and effective utilization of RBE in computer science, our findings suggest the following. Building up from inquiry/problem-based approaches and teaching of research-related skills in the earlier years, RBE can be more strongly incorporated in the advanced courses. In terms of the potentially most difficult area, research-based assignments, one vision is relate the frontiers to the state-of-the-art, and design the assignment to make progress towards the frontier. In terms of research project courses, students need to be set meaningful and manageable tasks, and the lessons from the ACSs mentioned above need to be adhered to.

If done in this way, the potential benefits of research-based education are considerable, in terms of higher quality pedagogical outcomes and enhanced student and academic experience. Surprisingly this is even important for vocationally-oriented degrees (.e.g. Software Engineering) as it has the potential to improve industry practice, since graduates will be more aware that research is shaping their industry and be more likely to participate in this as a result.

Future developments foreshadowed in this study could include a review of the computer science curriculum and degree structures. More sharing of relevant teaching practices and their evaluations, though seminars and scholarly papers, will also be helpful. Forming a Community of Practice of like-minded teacher-researchers in computer science is another way of achieving this; indeed such a university-wide Community is already established.

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A Appendix: A Model for RBE in an AI Course

The following is a vision for research-based education offered by one of the academic interviewees after the interview.

> Research means generating new knowledge, so research-led education means teaching students how to generate new knowledge. There is an important place for research-led education in undergraduate courses, less so in first or second year courses and more so at the senior level, of course. The main elements of research-led education are:
>
> 1. Making sure students are aware that sometime in the past any piece of current knowledge wasn't known and had to be generated at that time by some person or group (an obvious point perhaps, but still worth making).
> 2. Stating what the grand challenges are in a particular field (e.g., in robotics, building a robotic soccer team that can beat the best humans by 2050; in AI, achieving human-level intelligence).
> 3. Giving an idea of the current research frontiers in a field and what general problems researchers are working on now.
> 4. Explaining what constitutes good science as distinct from bad science (e.g., not all open problems are worth working on - even a full solution to many questions that one could ask would be a waste of time).
> 5. Giving some ideas about the approaches that researchers use to generate new knowledge (e.g., reducing a big problem to manageable subproblems, solving special cases and then attempting to generalise beyond these, doing experiments to try to shed light on theoretical foundations, trying to solve a mathematical conjecture by coming at it from as many plausible directions as possible, being prepared to spend days, weeks, months, or even years on the same problem, and so on).
> 6. Giving assignments (at a level suitable for the students) for which there is some connection to current research problems and perhaps even a plausible pathway to the solution of a grand challenge problem (e.g., an assignment for an aspect of planning for a robotic soccer team that uses cheap, currently available soccer robots).
>
> Students who have had a research-led education are more likely to be successful in an environment in which many people have several rather different careers in their working lives. They are also more likely to be critical of conventional wisdom and be better problem solvers.

B Appendix: Interview Plan for BCS Students

Note: the interviews were of an 'exploratory' nature and hence the following should only be regarded as giving an indication of the range of questions that were asked.

Your experiences of and approaches to study

1. Consider the situation of learning course material in order to prepare yourself to begin an important assignment. What sort of things do you do when studying for this purpose? What are you trying to achieve? (Please describe the example you were thinking of).
2. Can you give me a concrete example of something you have done recently in order to learn course material?
3. Consider the situation of learning course material in order to prepare yourself to begin an important assignment. What sort of things do you do when studying for this purpose? What are you trying to achieve? (Please describe the example you were thinking of).
4. Can you give me a concrete example of something you have done recently in order to learn course material?
   (a) Why did you do it this way?
   (b) What were you hoping to achieve?
   (c) Could you have done it in a different way?
5. Is your approach to study the same across all your courses and assessment items?
   (a) Can you give me examples of how your approaches to study differ from one course to another?
   (b) Does it depend on the styles of teaching, or the nature of the subject?
   (c) Can you give me examples of how your approaches to study differ from one assessment task to another?
6. What sort of things do you do when revising for an examination? How do these activities differ from your normal study practices?
7. Does it depend on the styles of teaching, or the nature of the subject?
8. Can you give me examples of how your approaches to study differ from one assessment task to another?
9. What sort of things do you do when revising for an examination? How do these activities differ from your normal study practices?

(please write a 1 paragraph summary on your responses to this section)

Your social/cultural/personal experiences of the BCS

1. Why did you choose the BCS?
2. What do you hope to get out of the BCS?

   item How would you describe your relationship with your mentor?
3. How would you describe your relationship(s) with other students enrolled in the BCS program?
4. How would you describe your relationship(s) with students in your courses enrolled in other computing programs (e.g. the BIT or BSEng)?

Your Experiences of Research-Based Education

1. Your program is called a 'research-oriented program'. What does that phrase mean to you?
2. What does the term 'research-based education' mean to you?

   item What examples of what could be termed 'research-based' education have you encountered so far?

   (a) How did you respond to them?

   (b) Was your approach to learning different?

   (c) Is there anything could have made the teaching in these examples more effective?

   (d) How would you compare your experiences of this with more traditional (e.g. curriculum-based) teaching?
3. What examples of 'research-based' education do you foresee for the later parts of your program?

   (a) How are your current expectations of these, in terms of learning outcomes and quality of experience?

   (b) How, if anything, do you see it giving you an advantage in future life?

   (c) Do you have any insights or suggestions on how teaching may be implemented to best facilitate this?

   (d) Would you like to see any additions or deletions of any research-oriented aspects in your current degree program?
4. In the context of your program, what do you see as the advantages and disadvantages of research-based education?

C Appendix: Interview Plan for Academics

1. What examples of what could be broadly termed ‘research-led or -based’ education in computer science are there in courses that you have been directly involved with?

   Note: this can include ‘problem-based learning’ or ‘inquiry-based learning’.

   (a) Do you think there were effective? In what ways?
   (b) What impact do you think it had on the students?

2. What other examples of ‘research-led or -based’ education in computer science education within the College?

   (a) Do you think there were effective? In what ways?
   (b) What impact do you think it had on the students?

3. What do you see as the relationship between teaching and research (the teaching - research nexus) in the context of computing at a university?

4. For an (undergraduate) student to be engaged in meaningful research, what kinds and levels of skills do you think are required?

5. The BCS is called a ‘research-oriented program’. What does that phrase mean to you? What impact do you think it has externally? Do you think this is a model that could / should be extended to other parts of our degree programs?

6. In general, what do you see as the potential gains and drawbacks, obstacles and opportunities, to research-led/based education in computer science, IT and software engineering degrees?

   Do you think it should be expanded into the CS curriculum? If so, how?