Combining Research and Teaching at The Australian National University

Peter Strazdins,
Research School of Computer Science,
College of Engineering and Computer Science,
The Australian National University

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1 Overview

- research-based education: concepts and views; ANU's vision
- research-oriented undergraduate degrees at the ANU
  - the PhB (Science) program and its advanced study courses
  - the Engineering and Advanced Computing Research&Development programs
- research groups and educational programs
  - Engineering and Computer Science
- examples of research-based education
  - case studies in 2nd year SE and Computer Systems courses
  - other examples in regular and project courses
- academics' perceptions of research-based education
- strengths and weaknesses
- conclusions

2 Research-Based Education: Concepts

- ways in which research may be introduced into university teaching:
  - research-led: curriculum dominated by staff research interests
  - research-oriented: learn about research processes, how knowledge gets created, and the ‘mind-set’ of a researcher
  - research-based: students act as researchers, learn associated skills, curriculum dominated by inquiry-based activities

  hereon, ‘research-based education’(RBE) can mean any/all of the above
- “teaching should be directed towards helping students understand phenomena in the way that experts do”
- problem or inquiry-based learning (PBL): engages student learning in the context of a (broad) problem
  - potentially fosters closer engagement, deeper understanding and generic, long-term skills

3 Research-Based Education: Views in the Literature

- e.g. the Boyer Report (1998) strongly advocates this for research-intensive universities
  - 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 and take internships
  - students participate in research conducted by their lecturers
- other studies are more cautionary, e.g.:
  - extrinsically (vocationally) oriented students may not respond well
  - many academics believe basic knowledge must be acquired first
- potential student benefits found to be dominantly positive:
  - teachers have enhanced 'knowledge currency', credibility, competence in supervision and enthusiasm/motivation
    (perceived drawbacks: reduced availability & effort put into teaching)

4 ANU's Vision for Research in Education

- ANU sees itself as a *teaching-intensive research institution*
- approach was formalized in 2004:
  - "education informed by recent research" through a range of "research-led degree programs based on interactive inquiry"
  - approach: critical inquiry, deep approaches to learning, reflective practice and research experience early in the degree
  - research leads to new ideas with rigor
- elements of research-intensive teaching at ANU
  1. bringing the latest ideas from research into teaching
     - showing how research is shaping the field
  2. learning through inquiry
  3. building on fundamentals
- goal: education for life-long learning, future-proofing our students' qualifications

5 The PhB Program: The Flagship Research-led Degree

- PhB (Science) program a “research-focused” Honours program
  - elite program (top 1% entry)
  - requires six advanced study courses (ASCs) over the first three years
    - often in form of research projects with an academic instructor
  - half-year Honours project in the 4th year
  - otherwise extremely flexible, course prerequisites often waived
- student experiences:
  - 1st year students saw challenge and flexibility the main virtue; older students cited the opportunities for research
  - students often develop meaningful relationships with their ASC instructors
  - perceived benefits of ASCs include learning generic research skills & the resulting personal development
  - usually results in high workloads for the students!
- students typically major on life or physical sciences, sometimes in CS

6 Our Answer: the Research & Development Programs

- also are elite programs (top 2% entry)
- the Bachelor of Engineering (R&D)
  - includes a Research & Development component
    - 2nd year Project Methods course (6 units), 3rd & 4th year projects (12 & 18 units)
    - aim is to obtain a flavor of research in the discipline areas and develop independent research skills
  - typical intake 15–20, mainly from interstate and overseas
- the Bachelor of Advanced Computing (R&D)
  - also includes an Research & Development ‘major’
    - 2nd year Project Methods course (6 units), 2nd, 3rd & 4th year projects (6, 12 & 24 units)
    - internship and 3rd year project with an R&D industry partner
  - first intake in 2012!
- Majors and Specializations available as per non R&D degree

7 Engineering: Majors and Research Groups

- both Schools in the College are organized into Research Groups'
- the Bachelor of Engineering has 48 unit Majors and 24 unit Minors:

major/minor name	corresponding research group(s)
Electronic & Communication	Applied Signal Processing
Mechanical and Material Systems	Materials and Manufacturing
Mechatronic Systems	Systems and Control, Computer Vision and Robotics
Photonic Systems	Semiconductor and Solar Cells
Renewable Energy Systems	Semiconductor and Solar Cells, Sustainable Energy Systems
Sustainable Systems	Sustainable Energy Systems

- the advanced (3rd and 4th year) courses from the Majors arise from the strengths of the research groups
  - enabling a unique degree offering and undergraduate experience!

8 Computer Science: Majors and Research Groups

- the Bachelor of Advanced Computing has the following 48 unit interdisciplinary Majors

name	corresp. research group(s)	cognate discipline
Computational Foundations	Algorithms and Data, Logic & Computation	Mathematics
Computer Engineering	Computer Systems	Engineering
Human-Centric Computing	Info. & Human Centered Comp.	Psychology / Arts
Info-Intensive Computing	Info. & Human Centered Comp.	Biology
Intelligent Systems	Artificial Intelligence	Psychology

- 24-unit 'Specializations' (advanced 3rd and 4th year courses) also exist for Algorithms and Data, Artificial Intelligence, Computer Systems and Human-Centric Computing
- 2nd–4th year courses in the Bachelor of Software Engineering reflect the Software Intensive Systems Engineering group's research

9 Case Studies of Research in Education: Software Engineering

- SE Group is active in Model-Driven Engineering research – through both academic and industry engagement
- reflected in the 2nd year Software Analysis & Design course:
  - strong emphasis on software modelling techniques
  - e.g. automating the translation of models
- the 3rd year Systems Design for Software Engineers course
  - prepares software engineers to work in large engineering project teams
  - taught as a series of modules by leading researchers and industry practitioners
    - cover the latest research and practice
    - e.g. systems thinking, architecture, safety;
      model-based systems and requirements engineering

10 Case Study: Computer Systems Experimentation

- the Experiments on the Memory Hierarchy assignment for the 2nd year Introduction to Computer Systems course (2008)
- reflected research into computer simulators (Mascots'05) and memory hierarchy performance (ICCS'03)
- students previously constructed in C a simple cache memory simulator
- using this, they investigated (peculiar) properties of the random replacement policy:
  - e.g. when repeatedly summing a vector, what is the miss rate when the vector is (a) twice and (b) four times the cache size?
- for the Memory Hierarchy assignment, the instructor extended the simulator with performance instrumentation
- sample question:

  Execute the command `cachesim3 lgC ...`*, for* $lgC = 15, \ldots 19$*. What levels of the memory hierarchy are responsible for each decrease in performance?*

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11 Case Study: Computer Systems Experimentation (II)

- with $C = 2^{lgC}$, this timed the performance of the (repeated) computation:

```
int x = 0;
for (i=0; i < C / sizeof(int); i++) x += a[i];
```

- example run of test program:

```
partch> cachesim3 15 ...
...
for C= 32768, 339.9 cycles/access
```

- collated results:

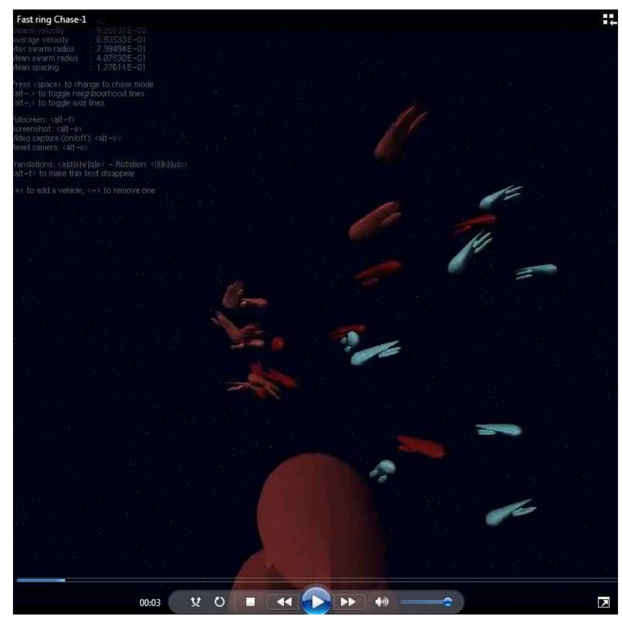
simulated cache size C	2^{15}	2^{16}	2^{17}	2^{18}	2^{19}
cycles/access on host	339	345	431	509	510

- sample answer:

We see a decrease in performance at $C = 2^{17}$, and again at $C = 2^{18}$. This, and particularly the latter, is due to L2 cache misses, as $C = 2^{18}$ corresponds to the cache size on the host machine.
Hardware performance counter statistics from the test program confirm this, and also show that TLB misses do not increase, suggesting the TLB has no effect.

12 Case Study: Concurrency and Swarming Behavior

- the 2nd year Concurrent & Distributed Systems course (2011) Gliding in Space assignment
- inspired by ANU research project in autonomous submersibles (Serafina)
- scenario: vehicles remain 'healthy' by staying in proximity of others in the swarm
- goal: keep as many vehicles alive as possible for as long as possible
- vehicles have built-in collision control and swarming behavior
- student task: set speed and desired destination to best maintain swarm
- Ada: with vehicle, task & message modules



13 Other Examples of RBE at ANU: Non-Project Courses

- teaching the process of discovery: Max-Profit Scheduling dynamic programming (DP) algorithm and associated proof (3rd year Algorithms course)
  - *Given a set of n jobs, each requiring processing time $t_i > 0$ and will receive a payoff $p_i > 0$ if finished by deadline d_i, select a subset to maximize total payoff*
  - discovery of the ‘Procrastination Lemma’ (an ordering of jobs by earliest deadline is optimal) from trying to construct counterexamples
  - discovering a subtle bug in first DP algorithm by checking against a ‘brute force’ algorithm
- problem-based learning: 1st year Introduction to Software Systems, group programming project
- 3rd year HCI course: studying key older research papers, then recent; also projects mirror research practice

14 Other Examples of RBE at ANU: Project Courses

- large variety of CS project courses, from 3rd year to Masters (implementation and/or research emphasis, 6 to 24 units)
- teaching generic research-related skills:
  - formation of a Community of Practice for generic skills (e.g. presentations, literature review, time management, writing, etc) for the CS single-semester projects
    - students benefited from each other's & the facilitator's experiences
    - learned in the context of their own and other students' projects: strong benefits in terms of motivation and experiential learning
  - recently extended the ideas to CS Honours research projects (2 semesters)
  - currently being considered for Engineering 4th year projects!
- project supervisors also support teaching of generic research skills, as well as discipline / topic - specific research skills

15 ANU Academics' Perceptions of Research-based Education

- RBE should include research that is of practical use to practising engineers in the next 0 – 5 years. It must be appropriate to the student groups – engineers or scientists
- the student skill level required for RBE: depends on sub-field (e.g. HCI easier); consensus is a good 3rd–4th year level but:

  clear thinking is the main thing; the need for specifics often over-rated
- for RBE, we should rethink our courses and set assignments accordingly, e.g. in an AI course:

  > *We could give a vision of 2050 with a World Cup class robot soccer team [the frontiers of the field]. 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.*
- to make it work: need attractive, high quality research programs and develop good rapport with u/g students (to retain them to p/g)

16 Strengths of Research-Based Education Approaches

- gives ANU a niche; it is what a research-intensive university should be doing!
- can recruit research students; can increase research output; raise the standard in industry
- can improve quality of teaching and learning
  - imparts enthusiasm; provides a unique, ‘cutting edge’ curriculum
  - forms broader & better thinkers (instead of tradesmen)
- often improves academics’ understanding / expertise in research area
- it is especially important for students to:
  - know that the discipline is evolving, that research is driving it
  - be nurtured for lifelong learning

17 Weakness of Research-Based Education Approaches

- for assignments in the large courses:
  - high staff workload to set up infrastructure and provide extra support
  - hard to make it work, especially for diverse student ability / interest
  - learning objectives may be unclear
- not for all students, especially at lower undergraduate level
- for project courses
  - our research interests too are sometimes specialized
  - unrewarding for all if students are sub-standard (or project timeframe is too short)
- in general, a considerable extra effort is needed for RBE

18 Conclusions

- in the literature, there are plenty of studies and relevant ideas
  - but as yet no direct comparison of traditional vs. RBE u/g degrees
  - the PhB and R&D degrees have enjoyed considerable success so far
- ANU's vision: seems appropriate for a research university
- Engineering and Computer Science majors reflect research group's interests and expertise
  - most 'advanced' 3rd or 4th year CS/Eng courses have elements of the respective groups' recent research
  - PBL approaches seem to work well
  - other RBE approaches have worked well for some 2nd year courses
  - explicit teaching of generic research skills works well for projects
- ANU has committed considerably to the approach and will continue to do so!