

TEACHING COMPUTER SCIENCE: EXPERIENCES FROM FOUR CONTINENTS

Mats Daniels
Dept. of Computer Systems
Uppsala University
Uppsala
Sweden
matsd@DoCS.uu.se

Judith Gal-Ezer
The Open University of Israel
16, Klausner St.
Tel-Aviv
Israel 61392
galezer@cs.openu.ac.il

Ian Sanders
Computer Science Dept.
University of the
Witwatersrand
Johannesburg
South Africa
ian@cs.wits.ac.za

G. Joy Teague
Deakin University
Geelong Campus
Victoria
Australia, 3217
joyt@deakin.edu.au

ABSTRACT

In this paper we compare and contrast computer science curricula in four universities in four different countries (and continents): Australia; Israel; South Africa and Sweden. Uppsala University in Sweden is a European university founded in 1477 with a long history of tradition. The University of Witwatersrand in South Africa and Deakin University in Australia evolved from 'Schools of Mines' (technical schools) in 1922 and 1977 respectively and have their roots in the British academic system. The Open University of Israel, established in 1974 by the Ministry of Education, began teaching in 1976. As new universities, Deakin University and the Open University of Israel sought to fill needs not met by existing universities, so both have concentrated on distance learning (off-campus) programs. For similar reasons, Deakin University and the Open University of Israel also provide special non-degree short courses and programs. We refer to undergraduate and graduate studies and consider degree requirements, methods of delivery, assessment, and costs. We also briefly mention such issues as programming languages and the development and evolution of programs of study and of individual courses in the four universities.

INTRODUCTION

While one might believe that the methods of teaching, ways of designing courses, systems of assessment, indeed the whole *modus operandi*, are the same among universities worldwide, we can report that this is not the case. In comparing the computer science (CS) departments at our home

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SIGCSE '96 2/96 Philadelphia, PA USA
©1996 ACM 0-89791-757-X/96/0002....\$3.50

universities, we did find similarities, but also noted many differences.

It quickly became apparent that different terminology is used, and that in different places the same word can have quite different meanings. For the purposes of this paper we standardized on the following terms:

- 'program' for a program of study leading to a degree such as a Bachelor of Science (BSc);
- 'discipline' for all material relating to the same scientific area, e. g. CS, information systems (IS);
- 'course' for a sequence of lectures, for example, CS1, the successful completion of which receives credit towards a degree; and
- 'topic' for specific parts in a course, e. g. the section on algorithms in CS1.

The four departments described in this paper are described below and compared in Table 1.

Department of Computer Systems (DoCS), Uppsala University, Sweden. Uppsala University is the oldest and second largest (approximately 30,000 students) in Sweden. There are several different programs where CS is either a major or minor (but substantial) part of the requirements for achieving a degree. Students residing in Uppsala comprise the majority of the student body, but distance education is also offered. DoCS has a large share of the distance students, with roughly 20% of the department's undergraduates learning at a distance.

Department of Computer Science, University of the Witwatersrand (Wits), Johannesburg, South Africa. The university originally served mainly local students and had very few students in residence. This is gradually changing, although residential students are still a relatively small percentage of the total student numbers. The university has approximately 25,000 enrolled students, most of them full-time students. The CS Department, originally a division of the Applied Mathematics Department, became a depart-

ment in its own right in 1981. The University also has an IS Department.

School of Computing and Mathematics, Deakin University, Australia. Established as the first country university in the State of Victoria, Deakin commenced operations with the programs and students of two antecedent institutions. Recently there have been mergers with other institutions and the University is now located on six campuses across a distance of some 180 miles. Rather than competing directly with the established universities, Deakin has concentrated on distance education, loosely modeled on the UK Open University. With approximately 51,500 enrolled students in 1995, it has the highest enrollment numbers of any Australian University, although about half of these are non-degree students. In 1995 Deakin University was named Australian University of the Year by The Australian Good Universities Guide for its innovative use of information technologies in undergraduate studies.

The Open University of Israel (OUI). The OUI is a distance learning university designed to offer academic studies to students resident throughout the country. It has an enrollment of more than 20,000 students. The OUI maintains a policy of open admission and its home study method allows students to pursue a higher education wherever they are located, without interfering with their personal and vocational obligations. Authorized by the Israeli Council for Higher Education to confer a Bachelors degree (only), the OUI offers more than 400 courses in Life Sciences, Natural Sciences, Mathematics, CS, Social Sciences, Management, Jewish Studies, Education, Humanities, Music and Art. With only 32 senior academic (faculty) members, the OUI has no faculties or departments. However, for all intents and purposes, the CS team functions as a regular department.

UNDERGRADUATE EDUCATION

Degree requirements

The composition of an undergraduate degree differs between countries. Uppsala University offers three, four, and four-and-a-half year undergraduate programs culminating in the awarding of either a Bachelor of Science (BSc) or a Master of Science (MSc) degree. The CS program emphasizes CS skills useful for the labor market. It includes Discrete Mathematics but very little Physics or Calculus. There are also two engineering programs (four and five years duration), containing less Discrete Mathematics and more Calculus and Physics.

In Australian and South African universities, completion of a three year undergraduate program earns a BSc, with an optional fourth year leading to a BSc with Honors, intended primarily for students wishing to pursue graduate studies. Unlike most South African CS departments, Wits offers a

Table 1: Department sizes

	DoCS	WITS	Deakin	OUI
Senior academics	13	10	12	5
Junior staff	15	–	4	20
Technical	3	2	3	3
Admin/secretarial	4	1	6	1
Full-time undergraduates	700	365	200	–
Part-time undergraduates	80	–	280	1300
Graduate research students	15	27	10	–
Off-campus graduate students	5	–	200	–
Total course enrollments	1400	365	2400	3000

BSc that is strictly CS — no IS component. The Wits undergraduate program teaches CS as a mathematical science and concentrates on theory somewhat more than on practice or applications. Deakin's program contains both IS and CS majors with common core courses, either or both of which may be taken. Originally Deakin's strong IS stream was unusual in an Australian university CS program. Now, however, many Australian CS departments offer IS.

An Honors degree at both Deakin and Wits can be followed by a (minimum one year) MSc, either by coursework and research report or by thesis (research only). Deakin and Wits both offer Diploma courses for graduates from other disciplines. The Wits Higher Diploma in CS attracts mainly science and engineering graduates. Deakin's off-campus Graduate Diploma of Computing has been popular with students from many backgrounds, but particularly teaching, wanting to learn about computers and/or to obtain a formal computing qualification.

The OUI offers its students a full-fledged CS undergraduate program and, recently, a CS and Management program. Although students learn at a distance and are part-time, the CS program, consisting of mandatory courses and electives, is compatible with programs offered by other academic institutions in Israel. It is equivalent to a three year full-time degree. The OUI is not yet authorized to offer graduate studies.

Structure versus flexibility

The greatest contrasts among the four programs were in the requirements for undergraduate degrees. At one extreme, undergraduate programs at Uppsala University and Wits are highly structured in the first two (Uppsala) or three (Wits) years, with effectively no electives. The factors in favor of this approach are: when new subject material is presented, it is known what previous courses have been taken; scheduling of lectures is more efficient; scheduling of student assessment dates for different courses is straightforward; and with few options, fewer courses are taught and fewer faculty members are required, although Uppsala

negates this benefit to some extent by repeating courses for other programs. A structured approach allows more material to be covered than in a more flexible program.

At the other extreme is the Deakin program. Under the Deakin University BSc regulations, there are no compulsory courses. Students must comply with prerequisites and must complete a major study. They can, however, take any courses offered by the University, with a maximum of one-third of their total courses permitted from other (non-Science) disciplines. This flexibility: allows students more time to decide on their major study area(s); permits them to avoid some courses in which they have little interest or ability; and allows students from other institutions (particularly Asian) to enter the program at higher levels with full credit for courses taken elsewhere.

The program offered by the OUI is balanced between structure and flexibility. On the one hand, it is structured; there are some mandatory courses and students are not permitted to take courses from other disciplines. On the other hand, it is the policy of the OUI learning system to allow students: to carry on with their studies for as long as they wish; to enroll in a course without completing recommended prior studies (although most students undertake courses in the recommended sequence); and to decide on their major after finishing about 60% (or even more) of their studies. This method allows students to pursue courses towards a Bachelors degree, or just to study course(s) in order to broaden their education.

Methods of delivery

In each of the four countries a full-time student is expected to spend approximately 200 - 300 hours in class each semester and at least the equivalent outside class. Students learning at a distance are expected to spend as much time in total studying a course as on-campus students.

Uppsala and Wits teach courses across a half semester (quarter). Advantages of quarter courses are that: academics have quarters free for research; students can concentrate on one or two courses at a time; and there is less conflict scheduling assessment tasks. At Uppsala, each week has its own schedule, making it possible to concentrate the teaching of basic theory early in a course and allowing plenty of time for completion of assignments.

At Wits the first year intake includes students from mixed backgrounds: good educational backgrounds with good familiarity with computer technology and programming; good educational backgrounds but with little familiarity with computer technology; and educationally disadvantaged students with little exposure to computing. In order to make the CS courses accessible to all students, Wits has

adapted its curriculum to present theoretical material earlier in the year (Mueller, Rock and Sanders, 1993). All students must have a minimum level of mathematics to enter the course and this common foundation can be built on, while introducing the less technologically familiar students to the technology before it forms part of their work requirements. Wits has also expended a lot of effort reviewing and revising approaches to teaching and learning (Sanders and Mueller, 1994). Wits offers a number of additional tutorials, at lunch times and on Saturday mornings, to give extra assistance to the educationally disadvantaged students who currently comprise about 30% of the student body. At the first year level the aim is to give a broad introduction to CS.

At Wits and Deakin, all on-campus students enrolled in the same course attend the same lectures. These large groups (several hundred in some classes) are divided into smaller groups of approximately 20 students for laboratories or tutorial classes which provide the only opportunity for group interaction. This approach has the advantage that academics spend fewer hours per week in the classroom.

Off-campus studies allow students, who are placed in a variety of situations that make on-campus attendance difficult, to complete degrees in their own time. Such situations include: working full-time, stationed overseas, living in remote regions, house-bound, or in prison. Off-campus courses are designed to meet the needs of individuals studying away from the university. At the OUI and Deakin, students are provided with: texts published by the university; assignments; tutorial guidance; study group sessions; tutoring by telephone; and a final exam. At Deakin, CS students are required to have access to a personal computer and a modem and to complete the same course requirements (with the exception of laboratory attendance and group work) as on-campus students. Students typically communicate with the course coordinator by phone or email.

The OUI is a multi-campus university with study centers throughout Israel. The textbooks are supplemented by tutorial assistance and study group sessions that take place in 90 study centers. More than 650 tutors throughout the country offer guidance and a personal link between students and the university. Tutorial sessions range in frequency from weekly to once in three weeks and are usually optional. The OUI has been integrating educational aids and technology since its inception. Some of its courses are accompanied by television broadcasts, slides, laboratory kits, etc. Over the last three years, much progress has been made in developing interactive studies via satellite, multimedia courseware, computer-mediated studies, and tele-courses. Beginners may enroll in only one course, but many later increase to this two or three courses per semester.

Recognizing the need to be more flexible and more entrepreneurial, the OUI, Uppsala and Deakin universities are all introducing summer courses. As stated earlier, Deakin and the OUI also offer non-degree courses.

Introductory programming language

In one area there is worldwide similarity: the inevitable debate that occurs whenever the subject of choice of the introductory programming language is raised. At Uppsala, Standard-ML (a change from Scheme this year) or C++ is taught as the first programming language (depending on a student's education program). Wits and the OUI use Pascal as their introductory programming language — it is a good teaching language and less obscure for educationally disadvantaged students or for students working mainly alone. At Wits, the major programming course (C++ from 1995) is in the second year Data Abstraction and Algorithms topic. At Deakin, after much discussion, C was introduced some four years ago.

Student assessment

In all four departments there is a heavy emphasis placed on a written final examination. At Uppsala University the final six hour examination provides the main, and sometimes the sole, contribution to the grade awarded for the course. Most assignments and laboratories are compulsory and often contribute to the final grade. Wits examinations are typically two hours per topic and taken at the end of the semester in which the topic is taught. The exam to coursework weighting is normally 60:40, although practical topics do sometimes increase the weighting of assignments and laboratories. Deakin University, in line with most Australian universities, typically holds three-hour final examinations. Deakin CS assessment is typically 30% progressive and 70% for the final examination. At the OUI each student must complete a battery of assignments. These are graded by the student's tutor. Some courses have additional requirements such as workshops, laboratory work, a programming project or seminar papers. Assessment is typically 30% for assignments, and 70% for the final (three hour) examination, or 30% for regular assignments, 30% for the project, and 40% for the final exam.

Uppsala University students are given two opportunities each year to retake examinations that they fail. At the OUI, in line with other Israeli institutions, students are given one opportunity to retake exams. To pass a course they must achieve a minimum grade of 60% in the examination, and submit a minimum number of assignments. Deakin University students are given a supplementary examination only if they have obtained at least 40% at their first attempt and good results in other courses. Wits students have no opportunity to retake exams they have failed. They are required to achieve a subminimum mark of 40% for each topic and

an average of 50% to pass each year of study in CS. At all universities with on-campus students, laboratory work is mostly supervised by honors and graduate students who generally are responsible for grading assignments.

Costs of completing a degree

No student fees are allowed in Sweden — not even for items such as a plastic card to provide entry to labs. The costs of literature and other study materials are, however, the responsibility of the students. Special loans are available to students who have passed at least 75% of a normal study load during the previous semester.

In South Africa, education is government subsidized and also partially funded by local municipality grants. Thus, the cost of a degree varies across institutions. Wits, as a result of its past opposition to the apartheid system, receives somewhat less overall funding and studying at Wits costs about US\$2200 per year of study. University scholarships and/or loans are available to most of the students on the basis of financial need. In addition private companies offer bursaries (scholarships) — normally based on academic merit although there is an increasing number of affirmative action bursaries — and banks offer special student loans.

The cost for Australian resident undergraduates is approximately US\$1500 per full-time year, with a discount for upfront payment. A minimum taxable income applies before any payment is required. An allowance of up to US\$200 per week and a loans scheme are available to those in financial need.

At the OUI, tuition fees per course are approximately US\$375, but this can change in accordance with a national policy covering all Israeli universities. Tuition fees cover the OUI textbooks, as well as the assignments, participation in tutorial sessions, and the final exam. University scholarships based on financial need or on academic merit are available.

Development of courses and the evolution of programs

At Uppsala, Wits and Deakin, programs are revised every four to five years with minor revisions by course coordinators, as required, between times. The OUI does a major revision every seven years. At all four universities, revisions take into account the requirements of local accreditation bodies, comparisons with other university programs in the country, and worldwide trends in CS programs, such as the recommendations of the ACM and IEEE (Denning, Comer, Gries, Mulder, Tucker, Turner, et al., 1988; Tucker, 1991).

At Uppsala, student course evaluations are used as indicators of a need for review by the teachers, the departments, and the program board (each program has a coordinator

who chairs a program board). The reasons for poor evaluations are discussed at both the departmental and the program board levels. The departments, are the main force behind course changes. However, major changes are discussed by the program board, where issues such as whether the changed course fits the program or affects later courses in the program have to be settled. Each education program board makes yearly revisions to all course descriptions and decides which courses to offer in the following year.

At Wits, courses are normally discussed by the whole department to establish the broad general principles. The academic(s) most likely to teach the course then draw up an outline which is again debated by the whole department before being accepted or revised.

The primary element of the OUI's study method is the printed text, meticulously formulated by Israel's foremost scholars and attractively illustrated to highlight and enhance learning. The text is designed to be the best possible 'written lecture' in the field, and as such, the OUI enlists the cooperation of distinguished faculty from other Israeli universities. The course preparation team includes senior academic advisors, writers, external evaluators, assistants, and editors. After approval by faculty members and the academic committee, every course undergoes a comprehensive process of refereeing, re-drafting and evaluation. The development of a course takes at least four years and costs as much as US\$250,000.

Deakin University follows the same method of development of materials as the OUI, but, with a much smaller budget. The course is written by the people who will be most likely to administer it when it is up and running, then it is professionally edited. With standardization of courses on- and off-campus and across campuses, the 'course-team' approach is now also being applied to on-campus course development and teaching.

GRADUATE EDUCATION

Uppsala University offers licentiate and doctoral degrees in CS. A licentiate degree nominally takes two years of course work and research (ratio 50:50) after an MSc, and a doctoral degree nominally takes four years of course work and research (ratio 40:60).

The undergraduate honors degrees offered by Wits and Deakin prepare students for higher degree research. The honors year consists of coursework at an advanced level, a literature review and a research report. An honors degree can be followed by an MSc — either by coursework and research report or by thesis (research only).

The Wits MSc degree is offered for both full- and part-time study. The MSc coursework generally relates to the lectur-

ers' research interests. Students taking the coursework and research option are required to take three or four fairly intensive topics each over a six week period. The topics are seldom lectured, most comprise reading and discussion.

Deakin University offers an MSc, a minimum of one year post honors, and a minimum three year PhD both by research only. A coursework off-campus Graduate Diploma of Computing, for students who already have a degree in another discipline, has been available for many years. In recent years a Graduate Certificate (equivalent to half a year of full-time study) and a Master of Computing Studies (equivalent to two years of full-time study and including a major project) have been introduced.

The OUI's first graduate program, an MSc program in CS is awaiting the approval of the Council for Higher Education.

SUMMARY

This paper has explored Computer Science programs in four different countries. As can be seen, there are commonalities as well as differences. Different methods suit different places, but increasing knowledge of possible choices is an important aspect of enhancing education anywhere. We hope that this paper will generate international interest in some of the approaches we have described and motivate further international exploration of educational issues such as: half semester courses; off-campus methods of study; development of superior undergraduate courses; computer-mediated courses; interactive TV methods of studies, support for students with disabilities, etc. Collaborations of this type may also increase exchange visits of both students and academics between countries.

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ACKNOWLEDGMENTS

The authors thank Vicki Almstrum for her critical reading and criticisms from an American perspective and Barrie Hesketh for his review of the paper prior to submission.