Improving science students problem solving skills

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Students' lack of basic problem solving skills is a frequent complaint heard from teachers, lecturers and especially employers. During the past five years, I have attempted to improve problem-solving outcomes in Curtin's School of Computing by

- presenting an intensive course on philosophy of science, the scientific method, induction/deduction/falsification, and the theories of measurement, classification, and time, to first year students; and
- changing assessment tasks (both assignments and the examination) to
discourage shallow, and encourage deep, learning.

The performance of second and third year students, who had completed the new first year unit, was noticeably better than prior cohorts, especially in advanced modelling and simulation subjects, where systems design - abstraction skills are especially important. Changes to assessment included fewer but more complicated assignments, the use of group assignments (to encourage teamwork and division of labour), and the replacement of the standard two-hour final examination with a 'take-home' exam (requiring about 20 hours to research and complete). Student performance improved significantly (the pass rate went from 75 to 100 percent) and student appraisals of the subjects also improved.

I am now introducing the use of material on the scientific method, and the evolution of scientific understanding, in short courses aimed at secondary and upper primary science and technology teachers.

Introduction

Most undergraduates in intensive science degrees have no interest in pursuing a broad, balanced programme of study:

Their desire is to "get in, get trained, get out and get a good job". We do a pretty good job of meeting these expectations. But are the students getting an "education" or just very good training? (Kessell 1992: p 8)

I have lamented elsewhere (Kessell 1996a, 1996b) that many undergraduate science and engineering degrees are so packed with 'facts', 'technical detail' and 'advanced widget-making' that they do not address adequately such basic issues as creative thinking and problem-solving skills (much less professional literacy and professional practice issues). A number of recent national employer surveys (including Australia 1992; Australian Association of Graduate Employers 1993) have also addressed these deficiencies. The Discipline Review of Computing Studies and Information Science Education (Hudson 1992) noted:

IT (Information Technology) professionals need to have an understanding of the cultural, social, legal and ethical issues inherent in these professional areas. There is a need to understand where the IT disciplines have come from and where they are heading and to appreciate philosophical questions and issues relating to the social impact of computing. IT professionals also must be aware of basic legal issues, particularly in the area of intellectual property, and understand ethical values that should be a basis for commercial activity (p.189).

In 1988, Curtin's School of Computing started offering courses in geographic information systems (GIS), via a Graduate Diploma in GIS and a GIS minor stream in the BSc (Computer Science) degrees [GIS includes computer mapping, spatial analysis, modelling and simulation, and decision support systems]. In 1992, a Department of Geographic Information Systems was established, with Curtin becoming the first university in the world to offer a bachelor's degree in GIS. I was responsible for the design of that degree.

During 1988-91, I had taught a core subject in GIS called 'modelling geographic information'; it dealt with the formulation, testing and implementation of hypotheses that could be used to perform a range of spatial analyses. It soon became clear that many students had little notion of: how scientific hypotheses are formulated, tested and rejected; the interplay and interactions amongst induction, deduction and falsification; what distinguishes a 'good' theory from a 'poorer' one; the basic premises of measurement and classification; or how science changes, grows and evolves.

I attempted to address these deficiencies in two ways. In 1992, I introduced a mandatory first-year unit, called Information Technology and Society, in which about half of the semester was devoted to the history and philosophy of science. When these students reached third-year (in 1994), I made significant changes to the third-year modelling and simulation unit - changes which undoubtedly made it more difficult, more demanding, and requiring a deeper level of understanding. A formal summative evaluation of these two changes suggested that student understanding and performance improved significantly (Kessell 1996b).

The remainder of this paper examines these two changes briefly, evaluates their impact on students' depth of learning and problem-solving skills, overviews student feedback, and suggests ways in which basic 'understanding of science' material can be incorporated into other secondary, as well as tertiary, subjects.

History and philosophy of science
... to provide students with an understanding of the scientific method, how science and technology change and grow, their impact on society and what might await the next generation. It also explores the nature of ethics, personal and corporate responsibility, time and space, the possible origin of the universe, and the evolving relationship among metaphysics, science and religion (Kessell 1996a: p.368).

We start with an intensive look at both the history and philosophy of science, with emphasis on the scientific method, induction, deduction, hypothesis formulation, falsification, and major paradigm changes from Plato to Hawking (using Ferris 1988 and Dixon 1989). We examine the views of Kuhn, Lakatos, Laudan, Popper and Feyerabend (using Riggs 1992). We delve into the theories of measurement, classification and time; in one tutorial, students have to arrange a box of 35 widgets into a hierarchical classification system; in another, we attempt to define "life" and "intelligence" {very few definitions of life exclude fire}! We discuss fail-safe software engineering in the context of Crichton's (1991) Jurassic Park, and debate the limits of technological solutions via Hardin's (1968) The Tragedy of the Commons. We compare and debate the possible origins of the universe and of life, and the anthropic principle, from the perspectives of Paul Davies (1992), Stephen Hawking (1988) and Peter Russell (1992). The atmosphere is intense, the reading list demanding and the tutorial method Socratic.

While the primary intent of this unit is to expose students to new ideas, concepts, and ways of knowing-to make them think-it also reinforces the communications skills taught in other units. Assignments include an essay on "how scientific progress over the past century has affected the way we perceive ourselves and our universe", an essay on the tandem development of software and hardware, and a short science fiction story that deals with any issue discussed in the unit. Students must also present a 20 minute talk to their tutorial group (and then lead the discussion for a further 30 minutes) from a list of authors including Fromm, Jung, Suzuki, Sagan, Asimov, de Bono and Feynman (amongst others). There is no formal end of semester examination.

Spatial analysis and modelling

The third-year unit Spatial Analysis and Modelling focuses on how descriptive and predictive models are developed and tested, as well as how GIS software packages can be linked with a range of physical, biological, environmental and social models to improve decision making in a range of fields. It replaced, in 1994, the somewhat less rigorous Modelling Geographic Information (that I taught from 1988-93).

Because its students were the 1992-entry cohort that had completed the Information Technology and Society unit, it was possible to spend a great deal more time, at a more sophisticated level, examining how 'real world' models are designed, built, tested, refined and implemented. Most students had a much better insight into what was and was not practicable; they were much more critical in discounting 'loose logic' and faulty thinking; they were much more rigorous in their formulations, articulations and expressions of simulation designs and applications.

We were therefore able to cover a wider range of materials, at a greater depth, than had been possible previously. At the same time, I became dissatisfied with many of the components of the prior unit's assessment (which included two, individually-completed assignments, a one-hour written midterm test and a two-hour closed-book final exam). It became clear to me that these assessment tools were, inadvertently, encouraging shallow learning: I'll give you the 'facts' in lectures, you'll work out the 'answers' in the computing laboratory, and then you can give me back 'the right answers' on the assignments and exams.

I therefore replaced the second (previously individually-completed) assignment with a much more complex group assignment. It required students, working in groups of four, to devise and partially implement a solution to a current state-of-the-science spatial modelling problem. It required much greater analytical thinking and insight than previous assignments. Its complexity required members of the group to partition the work carefully (or else it never could have been completed successfully). It also demonstrated that, while there were several potentially successful approaches to solving the problem, there was no right answer. Each group was also required to present and defend its solution, in front of the entire class, at the final lecture.

I concurrently replaced the standard two-hour written final exam with a 'take home' exam; I advised the students to allow about 20-25 hours to research, think about, and write the paper. Because students were not 'under the gun' of a two-hour time limit, they were able to research, contemplate, and evaluate alternatives. It is set such that it can not be completed successfully on a shallow level, because it requires the application of concepts covered in class to problems and issues not encountered previously; if the students do not understand the concepts, they cannot apply them to the "real world" problems given. The sort of questions that I could set on the take-home exam would not have been feasible on a traditional timed exam. For example, I could now:

- Require critical reviews of two or three recent publications in the field;
Results: Student performance

Despite the significantly increased difficulty and depth of coverage in the Spatial Analysis and Modelling unit, student results improved significantly. When the 'old syllabus' was taught, from 1988-93, the pass rate was approx. 75 percent. From 1994-97, the pass rate has been 100 percent every year (significantly different at p < 0.01), despite the lecturer and students agreeing that the new syllabus is much more difficult and demanding. Anecdotal information, from graduates, employers and students going on to higher degrees, suggest that their level of comprehension has improved significantly.

Taken together, these experiences all support Perry's (1988) view that students can progress along a "learning scale". At one end of this scale, students view learning as the process by which they acquire facts and recall them on command; all knowledge is absolute (that is, all questions have answers, which are either "right or wrong", and the teachers have the "right" answers) -- the teachers' role is to give them the facts in manageable portions, and their role is to give them back to the teachers in an unchanged form. In intermediate stages, students come to realise-often painfully-that some questions have several answers, which may be right, wrong, or indeterminate, depending on context; moreover, teachers sometimes "don't know the answers either", and their role is to guide the student in finding his/her own answers. The final stage is the student who realises that not only does his/her knowledge evolve with time, but that "absolute" knowledge and understanding is challenged constantly, and thus it evolves and changes, too. While this evolution of students' views of knowledge is imperative in a tertiary science faculty, it is, in my view, equally important as primary and secondary students development their own understanding and world view of "knowledge".

It is difficult - perhaps impossible - to separate the benefits from the history and philosophy of science unit in first year, from the role of the enhanced spatial analysis and modelling subject in third year, as all GIS graduates would have completed both subjects. However, several students from other degrees also completed the history - philosophy of science unit as a elective. As part of my recent MEd thesis, I conducted an anonymous survey of approximately 100 final year students and recent graduates; it addressed, amongst other issues, the impact of the first year unit.

Results: Student feedback

The vast majority of students responding to the questionnaire were extremely supportive of the first-year history and philosophy of science, how does science change and grow, and impacts of science and technology on society material. Comments (from Kessell 1996b) included:

Taking into consideration my current employment, I have found little use if any for the technical side of my education... The most common phrase used to describe Information Technology and Society is "it makes you think". It is most likely the only unit that teaches thinking skills... the unit encourages good thinking or reasoning skills by posing questions that our best philosophers have yet to agree on... In some respects, the unit also encourages diplomatic techniques. Students may try to solve difficult points in the discussion with compromise or by giving ground. The three units combined covered a very large portion of professional interaction. I feel I owe most of my education and knowledge to these units. (a graduate who is currently editor of a technical magazine)

Did the unit make me think? YES, A LOT!!!! In contrast to almost all the other undergraduate units that I undertook, only IT&S-152 made me think. The majority of the other undergraduate courses were simply either rote learning or hacking. If I didn't understand something in a unit, I would read up on it in the text book. In a sense, you are told what you should think (ie the text book is truth). With IT&S-152 I was taught to think. There are no wrongs or rights, and once I determined my stance on a particular issue, it was up to me to defend it by what ever means I had. (top student on Vice-Chancellor's List)

Since reading the assigned book, Ferris' Coming of Age in the Milky Way, I have read William Shirer's The Rise and Fall of the Third Reich, which has completely changed my views on war and government. The point is this: IT&S-152 presented me with material of a completely different nature to anything I had been fed for a long time, and not only did I enjoy it, but it motivated me to seek a broader knowledge under my own steam. My opinions on a broad range of subjects have changed over the last twelve months; while it may seem a bit much to attribute this to a single unit, I feel I can single out IT&S-152 as the point at which it began. (final year student who is at the top of this class)

The learning experience itself was a welcome relief from the routine rigours of the week. The concept of making people think is grossly underestimated by the boffins running Curtin. They fail to see that the positive stimulation received in these units rubs off on the units they want the results in. (mature age student)

The learning experience ... of these units was stimulating, challenging and useful in that it required the students to think for themselves. Many units provide the material in lectures in a boring "monkey see, monkey do" manner, whereas, the (three) units in question place all material before the student in an unconventional fashion, requiring the student to actually think to uncover the true meaning of the topic being covered ... since entering the workforce, I have found a use for most of the material presented in this unit. (mature age student)
I also conducted formative evaluations at the end of each semester; these included questions specific to the unit. For example, in response to the question:

- This unit attempts to integrate a number of themes, including:
  - History and philosophy of science;
  - Speculative questions concerning time, the history and future of the universe, the nature of life, and science vs. religion;
  - Hard-core issues such as where science and technology are now, and where they are going; and
  - Issues regarding ethics, intellectual property, professional responsibility and practice, and how technology affects individuals and society.

  How well were these issues addressed?

  all respondents replied with ‘well’ or ‘very well’.

When asked:

- The published syllabus aside, the intent of this unit is to make you think. Has it been successful?

  All respondents replied ‘yes’.

When presented with the statement:

- It has been suggested by some that Information Technology and Society is a ‘soft’ unit, not really relevant to scientists students, and should be abolished.

  98 percent of the students disagreed.

Unfortunately, when a new professor and head of school was appointed in 1996, the Information Technology and Society unit was cancelled, because it was ‘soft, not relevant to science students, and a waste of time’.

**Discussion**

I recognise that it is easy for critics to suggest that the improved outcomes, which I attribute to the teaching of history and philosophy of science, and the encouragement of higher-level learning via changes in assessment, can not be a proved causality. However, by using a range of evaluation instruments, and obtaining feedback from a range of stakeholders, I have attempted to minimise bias and misinterpretation (cf. Cook and Reichardt 1979; Ramsden 1992; Sanders 1994). Specifically, Armstrong and Conrad (1995: p. 24) note that 'triangulation (comparing information from several different sources) is the best guarantee of validity for any subject evaluation'.

What does strike me, as an important result of this evaluation, is that a willingness to try different methods of teaching, presentation, syllabus content, and assessment, is likely to offer improved outcomes. I certainly maintain that many science and engineering students attempt to learn about, and do, science, while lacking a fundamental understanding of what is science, how is it formulated, how are hypotheses formulated, tested, accepted, rejected, and/or modified, and how does science change, grow and evolve. I fear that some conservative educators, who are unwilling to address such basic issues as 'what are we teaching, how are we teaching it, and more importantly, why are we teaching it?', will continue to produce students that can recite the ‘correct answers’ without any real depth of understanding.

More recently, I have incorporated several elements of this 'how does science come about, and evolve, and grow' material in other subjects that I teach in the Faculty of Science. I have found it to be very effective in guest teaching that I do, on occasion, at local secondary schools. I have also incorporated the basics of this approach in a new professional development course, called Information Systems for Teachers, aimed at both primary and secondary teachers of science, mathematics and technology subjects. I would urge science and mathematics teachers, at all levels, to consider how this approach might enhance their own classroom teaching.

**References**


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