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The usefulness of a science degree: The 'lost voices' of science trained professionals (2005-0012)

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Abstract

This paper reports a study of science graduates who are employed in positions outside their discipline specialisation. The research was designed to uncover the reasons for them choosing to study science at university, the competencies they utilise in their work and their lives, and how these relate to their undergraduate education in science. The study is seen as important in that already about half of science graduates are in such positions and it is argued that there is a need in scientific and technologically based societies to have a greater representation of such people in decision making positions in government and industry. The directions for the science degree which can be drawn from the data gathered are congruent with those arising from other relevant studies. That is, that attention be paid to widely used skills, such as communication and problem solving, and to developing an understanding of science within its social and ethical context. An argument is mounted for considering the way the science degree is presented to potential students and to the general public.

Context

There is a need to rethink the purposes and nature of the undergraduate science degree. The pressure for such reconsideration comes from a number of sources. First is the failure to attract students into science degrees. Although this is acknowledged as an issue confronting western societies more generally, the emphasis in this paper will be on the Australian context as will be evident in the literature cited through the paper. Second is the changing nature of science practice and the changing nature of work generally.

Decline in student numbers

Research in recent years has shown relative declines in developed countries in the proportions of students studying science, engineering and technology at school, college and university (Ertl, 2003; Roberts, 2002; Department of Education Science and Training (DEST), 2003). For example, the Australian Department of Education, Science and Training (2003) reported that there has been a substantial decline in commencing enrolments in undergraduate courses in the physical and natural sciences between 1997 and 2002.
A failure to attract students into these areas of further study is resulting in a shortage of people equipped for positions requiring a high level of mathematics and/or science background (Parliament of Victoria Education and Training Committee, 2006). Within the science community itself there is alarm at the declining number of students opting to undertake science studies at the tertiary level. For example, the Royal Australian Chemical Institute has released a report on the supply and demand for chemists (RACI, 2005). The report notes, with concern, the decline in the number of

students taking chemistry at university, and the resulting strain on chemistry departments, often resulting in mergers.

Engineers Australia reported that Australia produces fewer engineers per head of population than other OECD countries (referred to in Parliament of Victoria Education and Training Committee, 2006).

Most of the arguments in such reports are framed in terms of countries' economic future and the associated need for a workforce with specialist science expertise, envisaged as filling technical roles in research and development, teaching, and applied science. We would argue that the argument should be framed more broadly than this. A case has been made (Symington & Tytler, 2004) for the importance of having people educated in science at the tertiary level in government and management, where decisions are being made about the future of the country, including science and technology related policy frameworks and funding decisions. Several of the participants in Symington & Tytler's (2004) study of the views of community leaders on the purposes of science education proposed that there was a need to act on this issue. If this argument is accepted there is a need to reconsider the purpose and hence the nature of a science degree.

The changing operation of science

As well as concern about the numbers and quality of students studying science there is disquiet that tertiary science education does not reflect effectively the nature of current scientific activity. There is no doubt that the way in which science operates has changed and is changing, for instance involving increased collectivisation and greater involvement with societal issues (Ziman 2000; Tytler & Symington 2006a).

There is a need to ask whether science courses accurately reflect the nature of science as it currently operates. It is not just a matter of getting more students into science degrees; it is also a question of the nature and quality of the education these programs offer, and whether they offer a valuable preparation for subsequent engagement with science related work and science generally.

Inputs into the nature of the science degree

As an outcome of this study we proposed to consider whether the content and practice within undergraduate science education is effectively matched to the needs and purposes of graduates, and of society more generally. The key question concerns the place of the science degree in the life and wellbeing of the country and its citizens. This is a question of purposes, and of how best to match the degree to these purposes. The questions are immediately raised; for what purposes, and for whose purposes? In order to pursue this agenda we need to ask where one should seek input into the conceptualisation of the science degree.

There are several ways in which the questions above could be addressed. Traditionally the purpose of the science degree has been to induct students into the discipline. The programs generated involved students being introduced both into the knowledge structures of the discipline and the methods employed to generate new knowledge (Academic science). However, the changing nature of the practice of science and its relation to society (Ziman, 2000) poses a challenge to this simple equation.

The position adopted in this study is that the purposes of the science degree should relate as much to the uses made of the competencies developed by graduates of the degree as to the demands of the discipline itself. Working from this perspective, Figure 1 suggests the sources of information and influence which should contribute to the conceptualisation of the science degree. In addition to induction into the current state of knowledge and practice in the disciplines of science (Academic science), the position we hold dictates that attention also needs to be given to broader aspects of contemporary science as it is practised in the community and industry (Science in societal and technological settings).

(Figure 1 about here)

Clearly the workplace of graduates must be a source of information when considering the science degree. However, in considering the needs of graduates in employment we are suggesting that it is not only the needs of those practicing their particular science specialisation (Specialists) that need to be considered. Attention also needs to be given to the careers of those graduates who work outside their discipline (Non-specialists). In recent studies (Anderson, McInnis & Hartley, 2003; Graduate Careers Council of Australia Ltd., 2004) the data indicated that about half of the sample of employed science graduates were in positions outside their discipline base.

Moreover, as has been argued earlier, a case can be made for attempting to increase the size of this group to ensure that scientifically literate people are involved at the decision making levels of industry and government. Hence we would argue that it is important that input from the world of work considered when devising undergraduate science education will include regard both for the demands of specialist positions, such as chemists in laboratories, but also for the demands of non-specialist positions where science graduates are employed.

As indicated also in Figure 1, attention needs to be given to the attractiveness of courses to potential and current students. In another part of the overall study being conducted, data have been gathered about attractiveness of science degrees to students. These data, as yet unpublished, indicate that programs need to project a very different image of science if the pool of people considering a science degree is to be increased. In particular, it was clear that high school students had little idea of the range of workplace possibilities opened up by a science degree, and equally clear that the type of course that would attract most students would be one leading to flexible, and multiple employment pathways.

Finally, it is proposed that attention should be given not just to the professional lives but also to the personal lives of science graduates. University education has in times past given significant regard to the notion of the broadly educated person. We are proposing that, while recognising the vocational purpose of the degree, issues related to the broader personal education of the individual should contribute to the conceptualisation of tertiary science education.

We are aware, of course, that these various sources of input and influence on the science degree interact in important respects, and this will become clear from the data presented. It is our hope, however, that the implications of these various influences are not contradictory, and that a coherent picture might emerge that is consistent with these multiple purposes and sources of information.

Current understandings

In considering the literature that can provide insight into what should be the nature and content of a degree in science, we will explore each of these sources of information in turn; the world of work, the world of science, ensuring attractiveness, and graduates' personal lives. It is clear that the relevant information will relate not simply to the nature of the knowledge to be gained from a degree, but also to the skills and dispositions that might be tackled. This review will focus both on findings that have implications for the nature of activities that should be part of a science degree, and research involving relevant innovations within existing degrees.

The available literature in this area is very uneven in quantity and quality. It comprises policy documents and descriptions of course developments in various universities, much of which would appear to be based on intuition rather than data, and some papers reporting research.

The world of science

Attention has been paid by various groups and individuals to the implications from the world of science for undergraduate science education. Professional bodies have contributed substantially to this type of study. The main issues of concern to such bodies are reflected in the recommendations of the Royal Australian Chemical Institute Report (RACI, 2005) related to university education (see Table 1).

(Table 1 about here)

These recommendations indicate that a major concern of this professional body is for the development of the knowledge and analytical skills utilised by many chemists employed within government and industry in positions specifically related to their discipline. Generally professional bodies focus much more on the demands of positions drawing directly on specialisations than those described here as non-specialist.

In companion research within our own study (Tytler & Symington, 2006a, 2006b) we interviewed focus groups of science practitioners working on priority research areas such as climate change, protecting the country from infectious diseases and pests, and frontier technologies. We found a significant emphasis on skills such as communication, analytic thinking and problem solving, and also on knowledge of the way science interacts with social and personal issues. This contrasts with the current emphasis within university science courses on knowledge, and technical skills.

There have been initiatives within universities which reflect a different perspective on what the world of science can contribute to curriculum design in science degrees. One example is a unit in a science degree at Monash University entitled *How Science Works* (Edwards & Ling, 2005). *How Science Works* encourages students to consider the social context of the discipline of science and to see science as part of everyday life. It structures learning experiences that 'promote reflection on the critical interface between science and the larger community'(p.2). As noted, linkages between university and science and industry were encouraged in the RACI report mentioned above, although probably with a different outcome in mind. However, there is no good reason why the two outcomes, greater competence in the practice of the specialisation and better understanding of the social application of the discipline, could not be achieved simultaneously through university/community science linkages. One might envisage a continuum that stretched from one emphasis to the other.

The workplace

There has been considerable attention paid to issues from the workplace more generally, in framing university education. In the last 20 years there has been a growing demand for higher education to meet more closely economic needs and employer requirements, (Bennett, Dunne and Carre, 2000). The Dearing report (National Committee of Enquiry into Higher Education (NCIHE), 1997) listed a set of skills essential for these purposes. These skills have been termed employability, generic, core, transferable key or lifelong skills.

However, the methods of arriving at identification and definition of skills valuable in the workplace are worth considering. In most of the documents surveyed these were arrived at through processes which did not include hearing from those practicing in the workplace. For example, a report on graduate skills assessment prepared for the Australian Department of Education, Training and Youth Affairs (DETYA, 2001) indicates that the skills incorporated into the test procedure were those deemed to be important by universities, and other stakeholders such as employers and career councils.

The key skills identified in the Employability Skills Study (Commonwealth of Australia, 2002) are listed in Table 2. The wording used in the 'explanations' makes it clear that the views expressed represent the voice of employers. It is worth asking whether these match accurately the views of those working within the organisations. Further questions are to what extent should tertiary education programs make development of these skills a priority, and whether there are special skills or other benefits that should be particularly focused on in a science degree?

(Table 2 about here)

In a recent study in Australia (Anderson, McInnis & Hartley, 2003) data from science graduates were used by the authors to draw conclusions about the nature and extent of employment – curriculum match or mismatch. The data were gathered by questionnaire from a relatively large sample of science graduates from six Australian universities. The items which elicited data about the use of skills and abilities developed in undergraduate education did not seek specific information about the particular skills and abilities being used, but used items such as “My job gives me the chance to use the skills and abilities acquired during my undergraduate degree”. Accordingly the data do not enable us to speak about specific skills and abilities. Further, the study focussed on the application of skills that the respondents believed they had developed during their undergraduate science degree and not on the full range of skills they were utilising in their work. It can be noted, however, that 60% of respondents indicated that their job gives them the chance to use the skills and abilities acquired in their undergraduate science degree.

A number of universities and university courses have accepted development of skills as a goal of the programs they offer. For example, Peat, Taylor and Franklin (2005) describe “some of the initiatives introduced into the curriculum of a first year science course…designed to help students develop the attributes required of a professional scientist” (p. 135). These attributes include the following skill groups: communication, interpersonal, information management, research, perspectives, business and personal.

The unit *How Science Works* (Edwards & Ling, 2005), referred to earlier, focuses on what are termed Monash Graduate Attributes. There is “a primary focus on critical thought and analysis and capacity for inquiry and research. There is a secondary focus on written and oral communication skills, teamwork, and effective use of information technology” (p. 2).

In summary, it is argued that although there has been a great deal of interest in this aspect of education for employment the information generally reflects employers’ views of desirable characteristics in workers and is relatively general in focus. There is a need to look more closely at this area seeking information from science graduates employed in a range of positions about the nature and relative importance of these competencies to employment and the nature of these competencies. There is then the further question as to whether it is appropriate to expect undergraduate programs to take the development of these as a key focus. The studies described above provide good models for the development of a wider range of outcomes than is normal within a science course, but they tend to be small scale and driven by enthusiasts. Is there a need to expand these, or related sorts of initiatives, to become major attributes of the science degree?

Student interest and patterns of choice

A major study has been undertaken by Macquarie University, Australia, into the attractiveness of science degree courses to students (Macquarie University, 2006). Data were gathered from a large sample of students in the senior classes of secondary schools by survey and a series of focus groups. Amongst the data were some which indicated the attitudes of these students to careers. The three most important elements in choosing a career were:

- A job that will benefit the community;
- A chance to interact with many people;
- A job with plenty of variety and challenge.

It was claimed by the authors that these were also characteristics of careers in science, engineering and technology. The important question, of course, for those wishing to attract school students into science degrees is whether students see this congruence.

Personal life

Although the literature on the purposes of school science education (for example, DeBoer, 2000; Symington & Tytler, 2004) generally places emphasis on the development of the learners in relation to their personal lives as a prime objective, there is little evidence from the literature that this features significantly in thinking about tertiary science education, apart from a commitment to producing a graduate with ability to be a life-long learner (Commonwealth of Australia, 2002).

The position taken in this study is that consideration of education to the personal lives of learners should not stop at secondary school level.

Research questions

As indicated earlier the study reported here is part of a broader one, which was designed to provide evidence relevant to the preparation of a new undergraduate, pre-service program for the education of secondary science teachers. It was expected that the students would complete degrees in both science and education. The study was built on a desire to see that there was coherence in both of these aspects of the students' education and that the developed program would prepare teachers who could provide a school science program which their students would see as relevant and interesting. Over the course of the investigation the emphasis shifted to the nature of the science degree, as a key aspect to be investigated.

The focus of this component of the overall study was on science graduates who held positions outside their field of discipline expertise (Non-specialists). We developed the suspicion that the competencies required of science teachers had much in common with those of other science graduates employed in non-specialist positions. We were interested to see whether the skills and attributes we reported as critically important for work in mainstream science research areas, are relevant for those graduates working outside specialist science. Our concern was to test the extent to which the needs of these two sets of stakeholders were aligned, and hence whether it might be possible to design a science degree which simultaneously met the needs of the two groups. The questions which guided this section of the study are:

- What factors influenced science graduates in non-specialist positions to undertake a science degree?
- What competencies do science graduates in non-specialist positions see as important in their working life?
- What impact does having studied science at tertiary level have on the professional and personal lives of science graduates in non-specialist positions?

- How could the science degree be framed to optimally serve the needs of these graduates working outside specialist science areas?

Data gathering and analysis

It was decided to gather data through personal interview. This appeared to be the most appropriate procedure where the focus of the research was broad.

Selection of study participants

There did not appear to be any simple method of establishing a representative sample. Universities do not have details of graduates and the type of positions they hold. Further, to locate study participants through professional associations would be difficult as the people we were seeking were those working outside their discipline.

Accordingly it was decided to use snowball sampling (Patton, 2002), recognising that caution would be needed in making claims about the representativeness of the sample obtained. Initially science graduates working in positions not tied to their discipline were identified through university alumni and personal contact. The initial interviewees suggested others who could be interviewed.

The size of the sample was not tightly determined beforehand but was influenced by the resources available for this component of the study.

Data were obtained from seventeen graduates. Three of the sample volunteered after reading about the project in a mail out to all alumni from one university, the other 14 in the sample were identified through personal contact, and had gained their degrees from a range of institutions. The data from three of those interviewed was discarded when it was decided that their current employment was too closely related to the discipline they studied in their undergraduate degree.

Pseudonyms have been used, but details of the participants whose data is utilised in the analysis are set out in Table 3.

(Table 3 about here)

It is recognised that the study involved a relatively small sample of people working in a limited range of positions and there is an issue concerning the extent to which the data gathered from this study are valid indicators of the wider population. While we acknowledge these limitations, we would suggest that the data be taken seriously for, as we shall show, it is broadly congruent with information from other sources. We would also argue that the study adds to this broader pool of information in that it speaks for the 'lost voices' of science graduates who do not work in areas directly related to their degree specialization but who constitute almost half of all science graduates.

The data gathering

The participants were each given a general overview of the process and the purpose of the interviews, as well as a brief overview of the overall project. The questions which had been developed as the basis of the interview were:

1. Could you give me a brief overview of your career trajectory?
2. What made you opt for a science degree? What did you know about career options before you enrolled?
3. What are the skills that are important to effectiveness in your working life?
4. To which of these skills do you think your science background has significantly contributed?
5. If you were planning a science degree for people who may work outside the lab/field work context what would you include?
6. In what ways do you think that your science training benefits you, if at all, in your personal life (including as a citizen)?

At the request of one participant an offer to complete the interview by e-mail was made and accepted by three of the participants. Two of the research team (A& B) conducted the interviews; one (A) interviewing eight study participants, the other (B) nine. The face-to-face interviews were semi-structured (Kvale, 1996) and took about one hour. One of the interviewers (A) audio-taped the interview and the transcript of the interview was sent to the participant for comment. The other (B) made notes and checked these notes with those interviewed. These procedures (member checking, Punch, 1998) established the validity of both sets of data. The study participants made very minor suggestions when asked to check the records and these were incorporated into the data.

Analysis of the data

Each of the two interviewers (A&B) made independent initial analyses of the data they had collected and they identified major themes which they saw emerging from the data and provided extracts from the transcripts to illustrate these themes. There was a great deal of commonality amongst the major themes identified, with both researchers identifying, for instance, communication as a major theme, and other categories differing only in level of detail (e.g. scientific thinking processes being unpacked to include analytical thinking and problem solving). There were, however, some differences, in part due to the relatively small size of each sample or the sampling process being used (Snowball sampling), and also possibly because of different frameworks being used by the researchers. To align these data sets, the total data set was analysed by two others in the research team, again identifying themes arising. The analysis was informed by the conceptual framework represented by Figure 1, as well as the research questions. The consequence has been that, while the major themes identified by the initial analyses remain, fresh perspectives have arisen that have been checked and verified by the interviewers, to result in an agreed, refined set of findings from the data analysis.

Findings of the study

The findings are presented as the themes arising out of this analysis process, illustrated in each case with interpretive discussion and illustrative quotes.

The careers of the participants

The career paths of the participants in the study are extremely varied. The only things that they have in common are that each has been employed in different types of roles, often beginning working in their field of specialization, and almost all have gained formal qualifications in addition to their B.Sc. degree. To illustrate the former point an outline of Kerrin's career is shown in Table 4.

(Table 4 about here)

The variety in career paths followed by the graduates interviewed is generally congruent with the findings of Anderson, McInnis & Hartley (2003) whose data indicated that 38% of the graduates completing the questionnaire, who were in both specialist and non-specialist positions, saw themselves in their desired career position whilst 47% saw their current position as a stepping stone to a desired career position.

The additional qualifications held by the study participants are shown in Table 5.

(Table 5 about here)

Again there is congruence with the findings of the Anderson, McInnis & Hartley (2003) study where it was found that, since graduating in science, a quarter of all respondents in the survey, which included people working in both specialist and non-specialist positions, had pursued a non-science qualification.

Conceptualisation of the science degree

The discussion of the data will be organized according to the sources of information proposed in Figure 1: student interest and patterns of choice, the workplace, the world of science, and the graduates' personal lives.

Student interest and patterns of choice.

Early in the interview the participants were asked what influenced them to enrol in an undergraduate science degree.

Commonly people interviewed for this study did not undertake a science degree for a specific purpose, or with a specific career goal in mind. In fact, several interviewees said that they simply f ell into science. Common motivations for undertaking science training seemed to relate to familiarity of science ideas from high school, personal interest, and a range of subtle (and not so subtle) parental and social expectations.

Familiarity due to undertaking science subjects in high school and enjoyment in previous school science learning was a common motivation for choosing science.

For example, Mat *did chemistry because I did chemistry in HSC. I just liked it at high school.*

For some people the key motivation for undertaking university science was a link with personal interests. For example, an interest in collecting encouraged Perry to study science. Pip undertook a science degree specifically to study geology, and relates this desire to family connections in the gem and fossil trade.

Social and parental pressures, both subtle and openly stated, did play an important role in some people's choice to undertake science at the university level. For example, Mike *got into the college of music and arts. I ended up coming to science because my parents said get an education then become a musician.*

Jess, Con and Sue illustrate the influence of prevailing perceptions of both the relative worth of science, and specific gender roles, as key pressures in their university path. Jess, for example, mentions that as she was part of the science stream of students in high school it was just accepted that she would move into tertiary-level science *…it was the general culture that you just wouldn't do an arts degree if you had the maths to get into science.*

Both Con and Sue felt pressures related to social perceptions regarding the role of their gender in science. Con mentions the fact that both the school and his parents promoted science as the correct course for boys to undertake *…overwhelming impression I got in high school was if you're a boy you do science….* He also notes his own values towards science in terms of the notion of the *…romance…* of physics and scientists.

Sue, on the other hand, recounts a story that reflects an active drive to include more girls in science:

I went to a girl's school, I was good at maths, and generally good at those subjects, and when I was at high school there was a big push for girls to do anything they want, and girls can do science…and because I liked maths as well as these subjects, I was sort of encouraged…but my real passion was to do art and graphics and things like that and my Dad said…'why don't you leave those and do them as a hobby'…(Sue)

Sue's story illustrates the complex interrelationship of the many factors that combine to motivate choice in taking a university path. In addition to the gender-based pressures and expectations, there was a parental perception that science training was more worthwhile than artistic endeavours, irrespective of their daughter's expressed interest. Sue also goes on to indicate that her choice of subjects within the science stream represented not her preferred science interest, biology particularly botany, but the fields that she felt more familiar with due to her secondary school learning.

Interviewees generally had difficulty in explaining their choice of which major subject they followed within their science degree. With the exception of Pip and Perry, who both had identifiable interests in the geological sciences, and Kerrin, who expressed her interest in the environment and outdoors which lead her to geology, many were not able to clearly define reasons for their ultimate study direction, stating for example that ... *I had no idea what I was going to do in high school.* (Mat), *I didn't know what I was doing the degree for, I had no idea…* (Dennis), and *I don't think before I did the course that I knew what geology was…* (Sue). In fact, several interviewees changed their study direction as they became exposed to alternative subjects during the early years of university, while others commented that by the time they did discover their real passion it was too late to change their study direction. Others, like Sue for example, discovered that although they did have an interest in science, their real passion or talent lay adjacent to, but outside the pure science field. Sue commented that she had always looked at rocks and natural formations, but:

> *…it had never occurred to me that I could learn about them, and when I started doing it* [geology]*, it just really drew me in……*
> *…what I've learnt about myself is that the thing that I like is learning, and that I like learning things that I'm interested in, so for me this was the type of learning that I liked….and I think that's why I became a teacher.* (Sue)

These insights demonstrate the two most common complaints expressed by interviewees regarding their science educational experience: firstly that career advice prior to beginning university was completely inadequate, and secondly, that even throughout their training there was little exposure to the relevance of the science and the probable or possible use of this in real work scenarios. Perhaps most interesting is that this comment was most vigorously made by those who undertook an applied science stream.

The vast majority of these interviewees did not enter science with a well-formed career outcome, nor did they often develop a career outcome during their study. The evidence from this study would suggest that a well developed interest in science is not a significant factor in determining the choice of area of tertiary study for people such as these who are working in non-specialist positions. Considerations such as parental views of job opportunities and success in school science would appear to be of more importance. This may not be the case, of course, for graduates who maintain careers in their discipline areas. This is, however, a potentially significant finding if we wish to target science degrees to attract a wider range of students.

The workplace

Despite the fact that the interviewees work in a range of environments there are some common themes in relation to the competencies they need in their working life. For the purposes of reporting here, these can be divided into two broad areas: those relating to use of scientific knowledge, and those relating to more general or generic science skills derived from their university experience of science learning.

Science knowledge: Several participants clearly utilize the scientific knowledge they acquired during their degree, despite not currently working in a laboratory or field environment related directly to their science training.

> *Where it helps, is when I'm in the witness box, in court, as I still do go to court as I do some case work. I can be a little more confident that any question they ask me, wherever it's going to lead me, I'll be able to answer it, even if it's a side*

track and they're leading me into lots of detail that's got nothing to do with the case, but at least I can be reasonably confident I'm going to be able to answer it. (Dennis)

Some interviewees indicated that much of the science knowledge they routinely use in their current employment was learnt in high school not at university (for example Jess and Mat).

Although noting these instances, most of the study participants did not talk about science knowledge as important to their working life. It would be unwise to make too much of this as people are not always aware of the difficulty they may have in fulfilling their role without their background knowledge of science content.

Generic skills***:*** In contrast to the minimal comment on content knowledge just discussed, all of the interviewees commented extensively on the importance of skills to their current employment role. Some indicated satisfaction with ways in which the degree program they had undertaken had prepared them in this regard. All pointed to ways in which degree programs could benefit by a greater emphasis on the development of these skills.

There is little doubt about the importance of communication for these people in respect of their employment. This should not be a surprise in the light of the literature on generic skills referred to earlier. The interviewees spoke about the need to communicate to various audiences. There was reference both to being required to write for people who work in a specialist field and communicating effectively with colleagues outside their particular discipline.

And communication is a huge part of this role. So if you can communicate with them in their language and understand how they think, that helps.
So even though the content of degree was not in agriculture, there is a common scientific form of communication that is important here. (Kerrin)

In my role I have to deal with chemists, meteorologists, computer people, managers, members of the executive sometimes, marine biologists and we have to understand each other. So it is very important to be able to communicate across the disciplinary boundaries. (Rick)

Much of the comment related to communicating with people who lack technical expertise, for example the general public. There were very useful comments made about the importance of the mindset needed by science professionals. The general thrust of the comments related not so much to the technical aspect of framing communication to be delivered to a non scientific audience, but rather to the need to engage with the public in a dialogue concerning science based arguments and the implications of science, and of being aware of the importance of the activity, such that public audiences would respond positively to what the scientists were doing.

…science communication is critical … you're going to be dealing with people who are affected by your science, and if you don't make that connection that what you

do as a scientist affects the community or it's going to affect somebody, then I don't think you should be doing science. (Kerrin)

I think there is a bit of a journey happening….I think when the world didn't agree with them, they used to do a, well if you don't agree with me on this scientific matter, then you don't have enough scientific knowledge, so we need to educate you and you will agree with me. But that doesn't work. …. I think when you are at school… knowledge is knowledge, its empirical, it is no or yes. If you talk to a scientist, they can't give you a no or yes on anything. And I think we end up having these long discussions on risk, and you have to be in the scientists' shoes to understand what risk has got to do with it. I think it is about, a scientist saying, ok, if you are asking me about my area and you are asking me something very specific so that I can give you an answer, and that really, whereas I think we need to look at other ways of how do we communicate about whatever choices our community needs to consider and make. I think that means doing that in a much more complex way. (Wyn)

In general the participants were critical of their lack of preparation for this activity in their undergraduate studies.

It would be really great if science students could give presentations and could actually write science articles. There was plenty of writing, but it was mostly to satisfy the requirements of the particular lecturer. The more you could mirror what the lecturer wanted to read the easier it was to get the required mark. It was not as if you had to stand in front of a community group and explain why a project was being done and convince people about it's worth, its value. (Rick)

Where there were positive comments they were about individual lecturers who ensured that students were given opportunities to develop skill in this area, rather than a systematic approach across their degree. The participants seemed to have lacked opportunities to learn about and practice oral communication skills and to write for audiences other than their lecturers and for purposes other than assessment.

If there was anything that taught me to public- speak it was my Human BioScience course because the lecturer was big on presentations, so we had, every week in our third year…to give five to ten minute presentations on a particular subject that we were given. We had to research it, come back, and we had to have a structure – she gave us specific things that needed to be put on, put in the talk, and each week she would critically evaluate how you went in your presentation – and I think that's given me the skills to be able to public-speak now. (Heather)

A number talked about the skills commonly accepted as being essential components of a science approach, for example, asking questions, handling and analysing data, inference and deduction.

I'd say the most relevant parts to my current working life would be just the ability to treat information in a methodical way. To be able to organise information; to be able to write concisely, in a scientific sense; to be able to make deductions, *conclusions based on facts and inferences, and these are just as important in my current job as they would be in a purely scientific job.* (Perry)

I do value being able to use that scientific method in a very general way in how I do my work–being able to look at the facts, and try to sort of work out a theory that seems to explain what we are observing…and making a sort of objective analysis from it. (Jess)

Problem solving skills…It's just the logical approach you take to trying to improve something – you look at analysing the data, figure out where your biggest losses are, focus on those losses, and that then takes more analysis because you pick one particular loss and you've got to analyse that in more depth–you just pick you way through the biggest losses until you get the improvement you need...the logical processes you follow. (Mat)

Dennis noted that in addition to contributing to his own work approach, his understanding of how to employ scientific processes enabled him to provide appropriate methodological guidance to his staff:

The way of thinking about a problem. As a manager I'm writing training programs, I'm writing method manuals, so I am actually applying the basic scientific methodology - overlaying that over forensic signal processing. (Dennis)

Although the issue of interpersonal skills was raised by the majority of the participants, most did not elaborate on what this entails. (This can be contrasted with the topic of communication where they all had a considerable amount to say.) Nor were they prompted to elaborate. One of the participants did speak in some detail of the requirements of his work place where effective teamwork was obviously very important.

You have to be able to understand how the team roles stuff works. For the team to work every one needs to know the other people's roles, it is possible for some one to say OK, I can come up with these ideas but I don't have to develop them through to completion, I can just have the idea and maybe I can do a few other things related to the idea but that is about it as far as my input is concerned. And then, on another team I may have totally different roles. (Rick)

It would appear that the undergraduate education of these graduates did not prepare them for this aspect of their employment.

Interpersonal skills in relation to a working environment – working with others….I can't say I learnt a lot of this from my course. (Con)

Although few participants in the study gave much credit to the contribution of their tertiary course to the development of skills, it is of interest that the skills they identify are mostly those associated with science. Little or no comment was made on some of those commonly identified as generic skills such as self management or planning and organising. This could be an artefact of the study context which the participants knew was about the outcomes of studying science at tertiary level.

The world of science

One of the issues raised by a number of the participants was the importance of students having exposure to the application of science in real world situations.

> *Definitely visiting industry and seeing the way theory is applied – that's the way to go.* (Dennis)

> *Have courses more linked to actual things…but need to have the philosophical and theoretical side…maybe having a balance of both.* (Sue)

> *..work experience, because the difference between anything you learn to the real world is just huge.* (Pip)

> *…..disconnected from what happened out there in industry.* (Con)

However, one participant warned against devoting time and energy to linking the science being studied to applications if it would lead to a loss of expertise in the discipline, suggesting that the application of the science could be learned in the workplace.

… need the theoretical science as a strong base for a scientist, and if you don't have that I don't think they can become very good scientists. I think that a lot of the other stuff you can learn after, and I think that's probably OK. (Kerrin)

Commonly those interviewed made comment on the importance of appropriate practical work within the degree program. There were specific suggestions about this practical work. Perry argued that tertiary science should ensure that it involved students in 'the full scientific process'.

> *It's very important that the students throughout that course are doing practical assignments which force them to think through problems in science and come to conclusions*." (Perry)

> *The most important thing I think, in the early years, is to do field work in earth science to actually see the theory where it's possible.* (Pip)

In summary the data indicate that generally the science programs to which the study participants were exposed had relatively little connection to the application of science outside the academic sphere; geology would appear to be one exception. The data provide strong support for practical work within the university and learning opportunities within industry. This is clearly in line with recommendations of professional bodies as illustrated in the earlier references to the report of the Royal Australian Chemical Institute (RACI, 2005).

Personal life

As indicated in Figure 1 it is proposed that the impact on individuals' personal lives could be a factor in determining the design of science degrees. Accordingly the interview schedule was designed to gather data on this issue and all participants were able to comment on the impact of the degree on their personal lives.

It was suggested by the participants that those who have completed science degrees are better equipped for their role as citizens in relation to science based issues. This was attributed both to the knowledge of the science behind the issues and to analytical skills and attitudes developed through an education in the sciences.

> *Look, I think anyone that does a science degree probably is a little bit more environmentally responsible than the average citizen because they know more about the implications of factors such global warming etc, and what happens when you chop down trees…….So in that sense I think a science degree does turn you into a better citizen if you like*. (Perry)

Some made reference to the impact of their science education on their personal activities. The contribution to their personal activities varied both in the activities identified and in the source of the benefit – some drawing attention to the benefits of the content knowledge whilst others pointing to attitudes and skills they had developed. Amongst the activities mentioned were the viewing of documentaries on television, the enjoyment of the natural world, and hobbies such as gardening.

> *…with news stories you can basically understand what they are all about so that makes things easier.* (Mat)

> *…I have a good understanding of why our garden looks like it is, and why we are having to plant certain plants and other things like that. (Jess)*

> *I suppose the only thing I did learn from bachelors was how to learn things. How to learn things easily and quickly. If I don't know something, I know where to find it, and I know without spending too much time. I know how to pick out information. That is probably one of my skills*. (Jane)

Two members of the group indicated that their science education had enabled them to have a well paid career.

> *I get paid very well!* (Mat)

> *My training has allowed me to pursue a challenging career which I have enjoyed whilst providing a good income.* (Grant)

Some interviewees commented that they highly valued going to university, and that much of their success in both their personal life and their employment is related to the whole university experience rather than just to the degree course they undertook.

University equipped me to be more critical, in a good way, more sceptical. It's made me more street wise, and more tolerant – different cultures, different lifestyles and different ways of thinking… (Dennis)

> *Other experience - thinking outside the square: culture, films, philosophy, music, news cannot be underestimated. I believe in my science degree this was too light on. It is a good grounding for life experience, and if such a degree is to be considered as a founding course to go on to do other things- it should be as such.* (Cath)

Whether such benefits are sufficiently significant to be taken into consideration when designing science undergraduate education obviously involves value judgements. However, it is valuable to be able to have some evidence, evidence that is relatively scarce in the literature, when making such judgements.

Implications of the findings

Before drawing implications from the analysis of the data we need to acknowledge that what can be said is to some extent limited by the sampling. As indicated earlier the method of selecting the sample does not allow it to be claimed to accurately represent science graduates employed in non-specialist positions. It is recognised that there are science graduates in many types of positions which are not represented here. However, what we do argue is that this sample gives insights which can be considered in conceptualising the science degree while recognising that a broader sample of careers might add to the available information. Nevertheless, some of the themes drawn out of the analysis were sufficiently widely represented in the sample to provide some confidence of their more general relevance.

The findings of this study suggest that:

- If science courses are to attract quality students in sufficient numbers, which is an issue occupying the minds of many concerned about the future in developed countries, the community generally needs to have a better understanding of science and how it operates.
- Science undergraduate programs need to accurately represent science as it is practised in the community, rather than focus exclusively on the structure of the discipline.
- Skills, which are included in lists of generic skills, particularly communication, working as part of a team, analytical thinking (often dressed up as the 'scientific method') and problem solving should be given greater consideration in designing tertiary study programs in science.
- University life should be seen as an opportunity to develop not just as a potential worker but also as an educated person: to restrict consideration to what is learnt in lecture theatres and laboratories is to miss some of the potential of a university education.
- When science faculties think about life-long learning they should recognise that for quite a number of the graduates this will not just be restricted to science. In

this study there was little reference to the importance of life-long learning in science alone.

- Science degrees should enable students to spend time outside the university in places where their specialisation is being applied. Students should have the opportunity to develop an understanding of science in its societal and industrial contexts.
- Science faculties should present a wider range of potential graduate destinations in advertising the B.Sc., and market the particular skills that the degree can develop.

Conclusion

An assumption behind this study was that in the science-based world in which we all live it is imperative that there are scientifically literate people in positions where important decisions are being made about the future of the society. One need only point to current debates about how to address the issue of global warming to illustrate the claim. Arising from this position we have argued that an important source of information for conceptualising undergraduate science programs are graduates who are currently in positions which are not specifically tied to their discipline expertise.

As indicated there is evidence that in Australia about half of science graduates are employed in such positions. In this study we have gathered information from a sample of such graduates. No claim is made that the data comprehensively represents the needs of people in all such positions. The sampling method used and the limited size of the sample place limits on the generality of the findings. However, the study draws attention to this group whose voice is often forgotten when considering the purpose and nature of the science undergraduate degree and has given some clear pointers to common needs.

One of the major issues which emerged from the data is the importance of some skills, for example communication and problem solving, in the workplace. Several points need to be made about this. First, the skills which were most commonly discussed by the participants of this study are frequently found in lists of generic skills (for example, Commonwealth of Australia, 2002). Second, and most importantly, earlier research (Tytler & Symington, 2006a) has shown that these same skills are identified as important by those working in specialist science fields. Putting these pieces of information together, it becomes clear that there is no need to advocate separate undergraduate programs in science for students with different career aspirations. Third, the means of addressing the issue within undergraduate programs are not complex. Rather they require an acceptance of the importance of skill development to graduates, including to an understanding of science, and the will to create opportunities within the program for students to practice and receive feedback on these skills. Fortunately, there are some useful models being developed around the world (for examples see Palmer, 2000). In arguing for this shift we are recognising the needs of the many graduates working outside their discipline areas. However, we need also to acknowledge the coincidence of the needs of these non specialising graduates, and those of discipline-specific scientists.

Another of the important issues emerging from the study is the desirability of learning science within the social and ethical contexts in which contemporary science inevitably operates. The study participants urged that students should have more exposure to the world of science in the community as part of their studies. Again this is consistent with messages coming from other sources. For instance, in the Tytler & Symington (2006a) study referred to earlier scientists operating within their own disciplines saw this as essential.

Thus far in this discussion we have been talking about the content of the science degree, in serving its dual purpose of catering for specialist and non specialist graduate careers. However, there is a more significant aspect to this issue, concerning the image of science and science degrees in the mind of the public. If, as has been argued, there is a need to have a greater presence of science educated people in decision making positions within the society, the science degree should be presented as a 'degree of choice' for people going into a wider range of careers and workplaces. There is an urgent need to break down the perception that science degrees only lead to careers in specialist positions in the laboratory or the field. A quick survey of university websites suggests that in selecting graduates to be profiled preference is given to those who move into roles which directly utilise their disciplinary expertise. We need a re-badging around diversity of employment opportunity. In doing this we should celebrate what is currently of value and promote this, but take the opportunity to extend and refine in a wider context.

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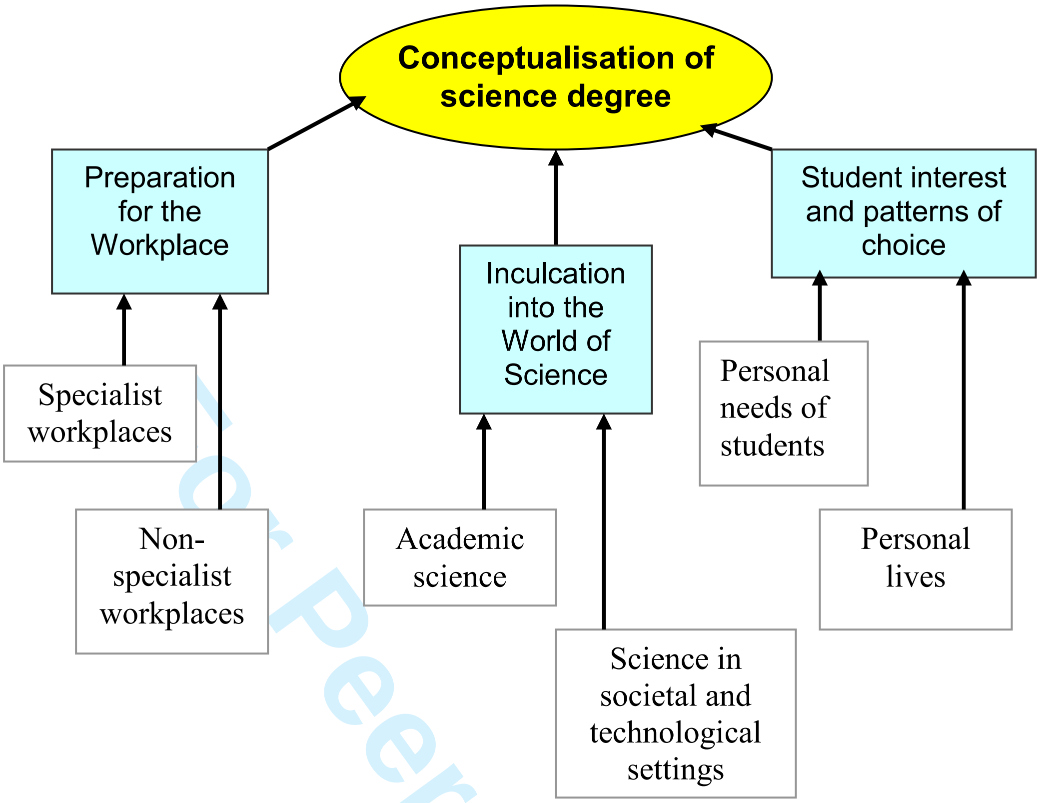

Figure 1. Sources of information which should contribute to conceptualisation of the science undergraduate degree

Table 1. Recommendations related to university education from the report *The Future of Chemistry Study* (RACI, 2005)

As many chemistry graduates are desired by employers for their strong analytical skills …….. the RACI recommends the following:

Recommendation 5	That there is adequate materials, equipment and physical facilities for students and university staff.
Recommendation 6	That every second year there is an accreditation of university chemistry courses with a focus on international best practice.
Recommendation 7	That more formal linkages are created between universities and industry.
Recommendation 8	That students undertaking chemistry have access to adequate information pertaining to potential careers in chemistry.

Table 2. Key Skills as identified in Commonwealth of Australia (2002)

Key Skills	*Explanation*
Communication	Skills that contribute to productive and harmonious relations between employees and customers
Teamwork	Skills that contribute to productive relationships and outcomes
Problem-solving	Skills that contribute to productive outcomes
Initiative and enterprise	Skills that contribute to innovative outcomes
Planning and organising	Skills that contribute to long-term and short-term strategy planning
Self-management	Skills that contribute to employee satisfaction and growth
Learning	Skills that contribute to ongoing improvement and expansion in employee and company operations and outcomes
Technology	Skills that contribute to effective execution of tasks.

Table 3. The study participants

Participant	Current Job Description	Degree	Major study
Grant	Contracts and Compliance Manager	B.App.Sc.	Scientific & Information Services
Jane	Human Resources Officer	B.Sc.	Statistics
Rick	Statistician	B.Sc.	Biology and Mathematics
Wyn	Grant Manager - government	B.Sc.	Biochemistry & Microbiology
Mike	Grid Research Programmer	B.Sc.	Chemistry
Sue	Secondary Teacher- science and maths	B.Sc.	Geology
Kerrin	Ministerial advisor- government	B.Sc.	Geology
Mat	Production manager—building materials	B.App.Sc.	Chemistry
Dennis	Manager—Police Forensic Division	B.Sc.	Applied Physics
Jess	Environmental regulations enforcement officer	B.Sc.(Hons)	Geology
Heather	Primary Teacher—classroom teacher	B.Sc.	Human Bioscience
Con	Primary Teacher—classroom teacher	B.Sc.	Applied Physics
Pip	Manager of government scientific research group	B.Sc.(Hons)	Geophysics
Perry	Manager of government scientific research group	B.Sc.(Hons)	Geology

Table 4. Outline of the career path of Kerrin, one of the participants.

- Completed a Bachelor of Science from university, immediately followed by a Master of Science
- Worked as a research assistant for a while when at university, then also worked as assistant to the head of the department at university: "and that was a similar sort of role – making sure he has what he needs to do his job."
- Started work as a scientist in her specialisation while still finishing the Masters Degree and stayed in that position for about eight years.
- Left to "take a secondment opportunity with the secretary, or CEO, of a government department and then worked there for eighteen months and really enjoyed the change – I thrived in that different environment."
- "So after doing that for eighteen months I decided I wouldn't go back to my original employer, and through that job I made a lot of networks, and I got offered here doing a similar thing but for the executive Director of Research in a government department." Kerrin at the time of the interview had been in this position for six months.

Table 5. Additional qualifications completed by the study participants in addition to their science degree

Diploma of Education (Note that two of the participants completed the Dip Ed but left teaching after a short period)
Honours year in science
Diploma in Audio Engineering
Graduate Diploma in Environmental Science
Master of Science
Bachelor of Education
Bachelor of Arts
Bachelor of Architecture
Graduate Diploma in Scientific Communication
Doctor of Philosophy