UNDERGRADUATE BIOTECHNOLOGY STUDENTS' VIEWS OF SCIENCE COMMUNICATION

ABSTRACT

Despite rapid growth of the biotechnology industry worldwide, a number of public concerns about the application of biotechnology and its regulation remain. In response to these concerns, greater emphasis has been placed on promoting biotechnologists' public engagement. As tertiary science degree programs form the foundation of the biotechnology sector by providing a pipeline of university graduates entering into the profession, it has been proposed that formal science communication training be introduced at this early stage of career development. The aim of the present study was to examine the views of biotechnology students towards science communication and science communication training. Using an Australian biotechnology degree program as a case study, 69 undergraduates from all three years of the program were administered a questionnaire that asked them to rank the importance of 12 components of a biotechnology curriculum, including two science communication items. The results were compared to the responses of 274 students enrolled in other science programs. Additional questions were provided to the second year biotechnology undergraduates and semi-structured interviews were undertaken with 13 of these students to further examine their views of this area. The results of this study suggest the biotechnology students surveyed do not value communication with non-scientists nor science communication training. The implications of these findings for the reform of undergraduate biotechnology courses yet to integrate science communication training into their science curriculum are discussed.

INTRODUCTION

Science plays a key role in the present global knowledge economy where economic growth increasingly depends on knowledge, information and higher level skills (Organisation for Economic Cooperation and Development, 2005). With the proposed convergence of biotechnology with nanotechnology, cognitive science and information technology, science is predicted to have an even greater impact on the lives of future generations (National Science Foundation/Department of Commerce, 2002). Surveys of attitudes towards science indicate that society, as a whole, are supportive of science and appreciate its value for continuing economic prosperity and quality of life (Smith, 2001). However, public concerns about the rate of emergence of new technologies and the ability of governments to regulate these new developments have generated significant tension between science and society (House of Lords, 2000) – tension which is predicted to increase as the pace of scientific development accelerates (American Association for the Advancement of Science, 2007).

In biotechnology, rapid advances have generated considerable controversy and public concern. While the governments of many countries see the commercialisation of biotechnology to be of benefit for society and the economy, not all members of the public share this view. Surveys of the public's attitudes towards biotechnology in America and Europe indicate that biotechnology raises a number of issues for the public, including the 'unnaturalness' of genetic manipulation, levels of acceptable risk and usefulness of new products (see Gaskell et al., 2000; Priest, 2000; Smith, 2001). In Australia, the federal government has examined attitudes to biotechnology in a series of biannual surveys (Eureka Strategic Research, 2005; Millward Brown, 2001, 2003; Yann Campbell Hoare Wheeler, 1999). These surveys suggest the majority of Australians see the application of gene technology as risky. In the most recent survey (Eureka Strategic Research, 2007), a majority (87%) of the 1067 Australians surveyed expressed the view that gene technology was likely to create “significant problems in the future” (p. 13).

Negative public perceptions of biotechnology pose a number of significant problems for the industry. Community resistance to technological advances have resulted in the rejection of products outright and the inhibition of research and development progress through bans and moratoriums. This has been particularly evident in the genetically modified food industry in Europe and increasingly in Australia (Smith, 2001). *AusBiotech*, Australia's national biotechnology industry organisation, has acknowledged that uncertainty about adoption of new biotechnologies by the community and regulatory bodies has prevented the Australian biotechnology sector from realising its full potential (Carroll, 2006). They noted that stem cell research and genetically modified crops, in particular, are areas that have failed to translate from advances in research to economic and social advantage. A decreased ability to attract secondary students to undergraduate biotechnology programs in Australia has also been attributed to negative public perceptions of the industry. The skills shortage that is predicted to result from this reduction in undergraduate biotechnology enrolments has been described as “one of the biggest threats” to the biotechnology profession (Lavelle, 2006, p. 20).

Increased recognition of the influence of public opinion on biotechnology policy, venture capital support, research infrastructure, and the ability of the sector to attract students has led to a stronger focus being placed on the communication of biotechnology with non-scientists. In 1999, the Federation of Australian Scientific and Technological Societies (FASTS, 1999, p.2) stated “that widespread public consultation and informed public debate be undertaken as soon as possible, with mechanisms for ongoing communication”. There have also been more general calls for all scientists to engage with the public in discussion and debate about the technical, and social and ethical aspects of research (Bodmer, 1985; House of Lords, 2000). Lane (1997) first termed coined the term ‘civic scientist’ to describe scientists who engage with the public in this manner.

While biotechnologists have responded to the charge to improve their civic science role, they have been accused of focusing public engagement activities on “modifying resistant anti-technology attitudes through education” (Hornig Priest, 2001, p. 97). It is now widely recognised that the assumption that objections to biotechnology arise from a deficiency of scientific knowledge is misinformed, and increased public understanding of science does not necessarily equate to increased acceptance of new technologies (Allum et al., 2008; Whitmarsh & Kean, 2005). While higher levels of scientific literacy are weakly correlated with more favourable attitudes to science overall, they do not always equate to more positive attitudes to specific technologies, particularly in biotechnology.

A lack of trust, rather than a lack of scientific understanding, is thought to be one of the most important factors in predicting opposition to the biotechnology industry and biotechnology institutions, such as scientists, industry, government agencies and the media (Hornig Priest, 2001). It has been suggested that the way to guarantee the “generation and maintenance of public trust” (Hornig Priest, 2001, p. 108) in biotechnology is through acceptance of public service obligation and improved interaction with the public (Whitmarsh & Kean, 2005). Rather than attempt to fill a perceived deficit in understanding about biotechnology, biotechnologists should aim to build trust in their profession and enter into discussion, dialogue and debate with the public about their research, show respect for public opinion, and accept public input into policy-making and scientific strategy. Clearly, this will require a cohort of biotechnologists who are willing and able civic scientists. These biotechnologists will need to appreciate the importance of science communication, understand its aims, and are able to effectively engage with the public.

Before biotechnologists may take on this civic science role, a significant number of barriers to involvement in science communication programs and activities may need to be overcome. The Wellcome Trust survey of UK scientists (Wellcome Trust / MORI, 2000) found a majority of scientists (60%) feel the day-to-day requirements of their job leave them with little time to communicate. In addition, one fifth of the scientists in this survey agreed that scientists who engage with the public are less well regarded by other scientists. The increasing specialisation and technical complexity of science (Boulter , 1999), the vast growth in the volume of scientific knowledge (Shortland & Gregory, 1991), and the culture of distrust of journalists and broadcast media (Triese & Weigold, 2002) are other significant barriers to civic science. To overcome these barriers and increase scientists involvement in science communication it has been suggested that a change in the culture of science is required whereby public engagement becomes an integral part of the scientific process itself, supported by formal acknowledgement of the importance of these activities and the provision of training (Wellcome Trust/MORI, 2000).

As tertiary science degree programs form the foundation of the biotechnology sector by providing a pipeline of university graduates entering into the profession, it has been proposed that formal science communication training be introduced at this early stage of career development (Royal Society, 2006). Graduates entering into mainstream research areas after this form of training may then be better placed to begin their careers as willing and able civic scientists. Little is known, however, about the state of science communication training in Australian universities or the understanding of science communication by biotechnology undergraduates. While a number of universities in Australia offer science communication courses and programs (such as the Australian National University and the University of Western Australias' Bachelor of Science (Science Communication), there has been no systematic analysis of the science communication training for biotechnology students in Australia.

A recent case study of an Australian biotechnology degree program has shown that some graduates of biotechnology programs may not be given any training in science communication during the course of their degree (Author, 2008). In this case study, a dedicated science communication unit was offered by the university, yet none of the biotechnology students elected to take this unit, only a minority of the lecturers were aware the university offered the unit, and very few promoted it as a possible elective for the biotechnology students to complete as part of their degree. The lecturers in the case study were unable to identify where biotechnology students are taught communication skills and the graduates felt their undergraduate studies did not provide them with any form of training in how to engage with the public.

This aim of the present study was to further examine this biotechnology program and explore in greater depth the undergraduate students' views of science communication and science communication training. This study asked the following research questions:

1. What is the level of understanding of science communication amongst biotechnology students?
2. What are the students' views of biotechnologists' roles in communicating with non-scientists?
3. What level of importance do these students assign to science communication training and how does this influence their participation in science communication training?

Given these students have received no formal science communication training during their degree program, the answers to these research questions will provide an indication of these students' level of understanding of science communication, whether science communication training is required, and whether they would be responsive to this form of training. Combined with ongoing research in this area, it is hoped that the results of this study will usefully inform those involved in the development of science communication training for tertiary biotechnology students, particularly those programs that have yet to formally introduce science communication into their program.

METHODOLOGY

Case Study

The research method was a case study (Stake, 2000) with mixed methods of data collection (Cresswell and Plano Clark, 2007). The study utilized both qualitative and quantitative data sources. According to Stake (2000) case studies arise from a need to understand complex social phenomena and provide a “rich and vivid description” of events (Hitchcock & Hughes, 1995, p. 317).

The present research study centres on an instrumental case study. This case design was chosen because, while the purpose of the study was to develop the issues, contexts and interpretations of tertiary science communication education in the particular tertiary biotechnology case chosen, ultimately the aim of the study was to generate a case report with recommendations that would be transferable to other tertiary biotechnology programs. Therefore it was important to select a program where aspects of the program were reasonably typical of other biotechnology degrees.

The chosen case study is a biotechnology degree program offered by an Australian university. The units offered in its program are representative of the combination of science and non-science content areas that characterise Australian biotechnology programs according to the description provided in the Australian Universities Teaching Committee's Review of Biotechnology (Gray & Franco, 2003, p. 16). A number of elective units are available to the undergraduate students enrolled in the program, including cross-disciplinary units offered by other faculties of the university. One of these cross-disciplinary elective units is a science communication unit. Offered by the arts faculty of the university, this unit is not one of the recommended elective units for the biotechnology program.

Case Study Design Quality

A major strength of the case study is the ability to build data triangulation into the research design and use many different sources of evidence for data collection (Yin, 2003). Elements of triangulation were built into the present case study by using multiple sources of evidence (questionnaires and interviews). Both qualitative and quantitative methods of data collection were employed. Proponents of this multi-method approach to research suggest that the use of mixed methods and the subsequent integration of different theoretical perspectives enable insights that may not otherwise be possible.

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Guba and Lincoln's (1989) criteria of credibility and transferability were used to maintain the trustworthiness of the research findings. The credibility of this study is reflected by the persistent observation of the case by the researchers. The first author was a lecturer in the program for seven years. For four of these years she was concurrently collecting data for this study and during this period maintained long-term observation of the case and stakeholder groups. An audit trail was also established to allow for the dependability of the case study to be determined. The transferability of this case report was taken into consideration when designing the case study. This study centres on a biotechnology program because this field of science is seen as *the* emergent technology of the century and thus it may serve as a useful model for other emergent technologies. In addition, biotechnology is a highly contentious and controversial area of science and there is a perceived need for biotechnologists who are capable of communicating the technical, social and ethical complexities of the field (Gregory, 2003). Through the choice of the particular discipline and the structure of the program it is anticipated that the findings of this case study will be transferable to other biotechnology programs, and potentially transferable to any other program involving the delivery of material linked to an emerging field of science which may involve technological controversy.

Instrument Design

Two questionnaires were designed for administration to undergraduate students in the degree program: a full questionnaire and a shortened version of this questionnaire. The full questionnaire comprised 17 questions: three dichotomous questions about degree program enrolment and sex, three open-ended questions about science communication and 11 rating scale questions comprising 55 items, which asked questions specifically about aspects of science communication and science communication training (see Appendix). The majority of the questions contained in this questionnaire were adapted from the UK survey *The Role of Scientists in Public Debate* (welcome Trust/ MORI, 2000). This full questionnaire was administered to students attending a lecture in a second year compulsory unit for biotechnology students, although students enrolled in other programs may enrol in this unit.

A second, shortened version of the questionnaire comprised the first six questions of the full questionnaire. This shortened version was administered to first year science students attending a compulsory unit for all students in the science division of the university. The unit has a large number of enrolled students. The logistics of distributing, allowing for completion time, and collecting a large number of questionnaires within a short period of time, dictated that the questionnaire administered to these students needed to be significantly shorter than the full questionnaire administered to the second year students. Third year students were also administered the shortened questionnaire in a third year unit for biotechnology students, which similar to the second year biotechnology unit, is also open to enrolments by students enrolled in programs other than biotechnology. As the lecturer of this unit was unable to grant any longer than a 15 minute period at the end of a lecture for data collection, the third year students were also administered the shortened version of the questionnaire.

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The rating scales contained in the questionnaires, also known as visual analogue or graphics scales (Oppenheim, 2001), were drawn as a 10cm horizontal line on the page immediately below each item in a question, and were bounded by a pair of labels that varied according to the question (unimportant – very important, strongly disagree – strongly agree, not responsible – very responsible). The respondents were instructed to “Indicate your response by marking a cross on the line”.

Graphic rating scales have been widely used in the literature (Friedman & Amoo, 1999) primarily because they are quick and easy to answer and quantify, but also because they do not restrict responses to a small number of discrete categories. The rating scale response format chosen in the present study was selected for these reasons but also because it represented an alternate response format to Likert scales. The students in the present case study are very familiar with Likert-type scales as a result of their constant exposure to teaching feedback surveys, and as a consequence may be at risk of providing responses without giving adequate thought to Likert scale questions or the responses they provide to these questions. Provision of alternate response formats such as rating scales have been described as acting as a “cognitive speed bump” (Harrison & McLaughlin, 1993), causing respondents to think in greater depth about the question and their response.

The rating scale response format was also chosen because it enabled a number of items corresponding to a single question to be aligned, thereby allowing students to rank their answers by visually comparing one response with the next (for example see Appendix question 17 in which 12 items appeared as 12 vertically aligned rating scales). Paired questions that required the students to answer a question in relation to technical communication and then social and ethical communication (for example see Appendix questions 7 and 8, and questions 9 and 10) were paired on a page with the rating scales vertically aligned, allowing the students to compare their responses to items within a question and items between the paired questions.

Piloting the Full Questionnaire

To improve the construct validity of the questionnaires (Oppenheim, 2001), the questionnaire was piloted with four undergraduate science students from another university. One student was in the first year of their degree program, and other three were in the second year of their program. The questionnaire was administered to the pilot subjects in exactly the same way it was to be administered to subjects in the main study. After completing the questionnaire the subjects were interviewed and asked for feedback to identify any ambiguities in the questionnaire and whether or not they found any of the questions difficult to answer.

The results of the pilot interview analysis indicated the subjects took an average time of 12 minutes to complete the questionnaire, found the format and instructions for the questionnaire easy to follow, and had no difficulties in responding to the questions using the rating scale format. While one subject indicated she would have preferred questions with a Likert-type response format, another indicated she liked the rating scale format because she it allowed her greater flexibility in her responses.

Any terms the subjects found difficult were discussed. These included ‘non-specialist public’, ‘media representatives’, ‘funders’ and ‘campaigning groups’. All of these terms were chosen for consistency with the terminology used in the Role of Scientists in Public Debate survey (Wellcome Trust/MORI, 2000). After discussion with the pilot subjects it was agreed that misinterpretation of the terms ‘funders’ and ‘campaigning groups’ could be minimized by providing an example immediately following these terms in the questionnaire. In addition, the terms ‘non-specialist public’ and ‘media representatives’ were replaced with the terms non-scientists and journalists, respectively. For two items in the questionnaire, the term non-specialist public was not changed to non-scientist. These items were linked to the question “How would you rate the importance of communicating biotechnology research with the following groups?” As a number of the groups included as items in these two questions could be regarded as non-scientists, the term non-specialist public was retained.

Analysis of Quantitative Data

The rating scale responses in the questionnaires were scored by measuring the distance in cm (to the nearest mm) from the left hand end of the line to the centre of the subject’s cross on the line. The results were entered into a Statview spreadsheet (SAS Institute Inc). As respondents are thought to be unable to make discriminations that are finer than ten points or so using rating scales (Miller, 1956), the data was collapsed into 10 categories (0-9) by transforming the data into its absolute value. The resulting ordinal data was then analysed using non-parametric tests in Statview (Huck & Cormier, 1996). For comparison of independent items the Mann-Whitney U test and Kruskal-Wallis one way analysis of variance test were applied to the data. For comparison of the rating of items related to the final question the Wilcoxon matched pairs signed ranks test and Friedman two way analysis of variance of ranks tests were used. Bonferroni adjustment procedures were applied to all post hoc analyses. Box plots were used to represent the rating scale responses (Huck & Cormier, 1996). For paired questions, responses have been presented as two sets of box plots within a single figure to allow for comparison of items between and within these questions (for example Figure 1).

Follow-up Interviews

To obtain a better understanding of the reasoning behind the students' responses provided in the questionnaires, 13 of the 23 second year undergraduate biotechnology students were interviewed. The students were interviewed during a laboratory session and consequently a number of students were unavailable for interview due to the timing of their experiments. Each student interviewed was asked to complete the questionnaire and explain their responses. The interviews were transcribed verbatim and each interviewee was assigned a pseudonym. The transcripts were entered into NVivo and coded (QSR International, 2002).

RESULTS

Full Questionnaire

The full version of the questionnaire was completed by 52 second year students, of which 23 were enrolled in the biotechnology program (see Table 1). The follow up interviews examined 13 of these students' responses to these questions. As this study is concerned with the responses of biotechnology students, only the results of the biotechnology students are presented in this section. The responses to Questions 1-6 of the questionnaire for both the biotechnology and non-biotechnology students are presented in the following ‘shortened questionnaire’ section.

[Insert Table 1 about here]

Awareness of Available Science Communication Training

The biotechnology students were asked in the questionnaire if they were aware of the science communication unit offered by the University and if they intended to enrol in this elective unit. None of the students had enrolled in the unit, and less than a quarter indicated they intended to enrol.

Understanding of Science Communication

The biotechnology students were also asked to define science communication in their own terms. The aim of this question was to determine these students’ understandings of science communication in light of the level of training they receive in this area. A definition of science communication had not been provided to these students or discussed with them prior to the questionnaire. Difficulties in defining science communication, and public engagement in particular, have been acknowledged in the literature (Royal Society, 2005; Stocklmayer, Gore, & Bryant, 2001). Given the complexity of the term and the lack of science communication training these students receive, the students were not expected to generate a comprehensive definition of science communication. Rather, this question was asked to determine the students’ understanding of the scope of the term (Does science communication include scientist-to-scientist communication and public engagement?) and its purpose (What should science communication aim to achieve?).

Five of the biotechnology students either left this question blank on the questionnaire or indicated they did not know how to define this term, by writing comments such as “I don’t know”, or providing a non-specific answer such as “the communication of science”. Of the 18 students that attempted to provide a definition of the term, six indicated by their answers that they felt science communication is limited to the communication of scientific knowledge between fellow scientists. For example one student defined science communication as “Writing review papers, lab reports etc that communicate your thoughts and understandings to the scientific community”. There was no indication by the biotechnology students of the potential for scientists to communicate science with audiences broader than their peers.

Only 12 of the 23 biotechnology students surveyed indicated the potential for the engagement of non-scientists in science communication, and only two phrased their responses to suggest this form of communication could involve an active exchange of information between scientists and non-scientists. One of these students wrote “It means how to communicate science with the public”. The remainder used language suggestive of a one-way transfer of information from scientists to a passive audience of non-scientists. One student emphasised in his written response that this one-way information transfer should aim for public acceptance of biotechnology, stating science communication is “communicating the aspects of science to the mass population for social understanding and acceptance”. Another defined science communication as the “transmission of scientific knowledge and news to the community”.

Views of Science Communication

The biotechnology students were also asked in the full questionnaire to give their views of science communication and biotechnologists’ role in communicating with non-scientists. One rating scale questions asked the students to rank two adjacent items (i) how important they feel it is that non-scientists understand the technical aspects of biotechnology, and (ii) how important they feel it is that non-scientists understand the social and ethical implications of biotechnology. Most of the students (18/23) indicated that they felt both items were important by providing rating scores of five or over. When these two items were compared, it was found that the students ranked the social and ethical item significantly higher in importance than the technical item ($Z=2.798$; $p=0.005$).

When the reasoning behind these responses were explored in the follow-up interviews, three of the 13 biotechnology students interviewed indicated they felt the communication of technical details with non-scientists was less important than communication of the social and ethical implications because non-scientists may find the technical details of research too difficult to comprehend. For example, when asked why he rated the technical item lower than the social and ethical item, Sam said “It would just go straight over their head what you are talking about”.

The questionnaire also asked the biotechnology students to rate the success of a science communication activity according to four possible outcomes (improved awareness, understanding, debate or acceptance of biotechnology products and processes by non-scientists). According to the responses provided to these four adjacent items, the students do not draw any distinction of success based on these outcomes ($H=2.381$; $df=3$; $p=0.4905$).

In the follow-up interviews, however, there was a clear indication that the most successful outcome of science communication was the improved acceptance of biotechnology. Just under half of the biotechnology students interviewed (6/13) stated this directly or indirectly by linking acceptance with the outcome they rated as most successful. For example, two students linked the improved understanding of biotechnology with improved acceptance. Jessica stated "I think they need to understand the social and ethical, so that we understand it, they understand it and they allow us to do our work". Nadine said "Acceptance, I think, sort of shows more that they have understood and they are happy to go with it."

As well as acknowledging a role for science communication in improving non-scientists understanding of research, the biotechnology students also acknowledged in the full questionnaire the importance of biotechnologists taking an active role in communicating their research (As seen in Figure 1). When asked to rate the importance of biotechnologists, science communicators, government, journalists and campaigning groups in communicating the (i) technical aspects and of biotechnology research to non-scientists ($H=46.217$; $df=4$; $p<0.0001$) and (ii) the social and ethical implications of biotechnology research to non-scientists (H=21.883; df=4; p=0.0002) using adjacent rating scales, biotechnologists were included within the most important groups for communicating. Science communicators were also given the highest rating for communicating biotechnology research.

[Insert Figure 1 about here]

The biotechnology students were also asked in the questionnaire who the intended audience for science communication efforts should be. With the exception of journalists, the students ranked the public as significantly less important targets for communication than the other adjacent groups listed as items (As seen in Figure 2; H=62.959, df= 5; p<0.0001).

[Insert Figure 2 about here]

The follow-up interviews indicated that the biotechnology students saw communication with scientists, government and the biotechnology industry as an essential part of a scientist's job, as opposed to communication with non-scientists and journalists which was seen as an "optional extra". Jim indicated he would only communicate with the public if approached by an "interested" individual. He stated:

> Well, I think it is important to communicate to other people in the field but I really don't think it's for the public unless they are interested……I think it would depend on whether the non-scientists were really interested. So I

> actually wouldn't say that they had to go out and actively tell them. The onus is not on them to go out and tell people what they are doing. I mean why would they do that?

Over half the biotechnology students interviewed (7/13) indicated they would restrict communication with journalists because they felt they were biased and would not accurately represent their views.

Shortened Questionnaire

The main focus of the shortened questionnaire was to establish the value biotechnology students in this case study attribute to science communication training, and compare their responses to students enrolled in other science programs. The students were asked to rate the importance they attribute to science communication training in relation to other components of their program. The shortened questionnaire was collected from 236 first year students of which 17 were enrolled in the biotechnology program and 55 third year students of which 29 were enrolled in the biotechnology program (see Table 1). As the first six questions of the full questionnaire were identical to the shortened version, the responses of the second year biotechnology (n=23) and non-biotechnology (n=29) science students have been included in this section. The relevant responses of the 13 biotechnology students who participated in the follow-up interview have also been included in this section.

In total, the questions contained in the shortened version of the questionnaire were collected from 343 undergraduate science students. Sixty nine of these students were enrolled in the first, second or third years of the biotechnology program. The remaining 274 students were enrolled in other science degree programs: biomedical science (n=50), molecular biology (n=66), forensic biology (n=10), veterinary science (n=47), biological science (n=43), conservation biology (n=36), or other science degree program (n=22). These 274 students were combined into one category labelled ‘non-biotechnology programs’.

Views of Science Communication Training

There were no statistically significant differences in the mean scores of the responses provided by the 69 students enrolled in the biotechnology program compared with the 274 students enrolled in the non-biotechnology programs (As seen in Figure 3) with the exception of two items, *Technical skills* ($Z=-2.844$, $p=0.0045$) and *An awareness of the public’s perception of the risks associated with research and research outcomes* ($Z=-2.085$, $p=0.0371$). *Skills in communicating research with non-scientists* was rated as one of the lowest four items by students in both the biotechnology program and the students in the combined non-biotechnology programs.

[Insert Figure 3 about here]

All subsequent analyses were performed using only the data obtained from the first, second and third year biotechnology students. Although further analysis of the responses of the non-biotechnology science students was beyond the scope of this study, it is possible that groups of students enrolled in degree programs other than biotechnology may have similar views of the relative importance of these curriculum items to the biotechnology students.

When the responses of the biotechnology students were compared there were no statistically significant differences in scores for the *Skills in communicating research with other scientists* item according to program year group (H=1.469, df=2, p=0.4733) or sex (Z=0.604, df=1, p=0.5452). Similarly, there were no statistically significant differences in scores for the *Skills in communicating research with non-scientists* item according to program year group H=0.399, df=2, p=0.8187) or sex (Z=0.1.742, df=1, p=0.0818).

The distribution of the curriculum items fell into four significantly different categories according to the level of importance attributed to them by the biotechnology students (H=392.123, df=11, p<0.0001). Post hoc analyses indicated the biotechnology students ranked *Technical skills* and *Knowledge about biotechnology* and *Communication between scientists* as the most important components of their curriculum (median scores of 9.2 to 8.8). Significantly lower importance was attributed to the second category of items which included *Broad science knowledge*, *Data analysis*, and the items related to misconduct and ethical issues (median scores of 8.3 to 8.1). The third category of items, included *Skills in communicating research with non-scientists* and *An awareness of the public perception of risk* (median scores of 7.6 and 7.7, respectively). And the fourth category, *Intellectual property* and *Business and marketing skills*, were rated significantly lower than all other items listed (median scores of 6.45 and 5.75, respectively).

The13 second year biotechnology students who participated in the follow-up interviews were asked to explain their rating of the two science communication items. All of the students interviewed indicated they felt *Skills in communicating with research with other scientists* was an essential skill for biotechnologists to have, and rated this item as one of the top three most important items for inclusion within their program. In contrast, *Skills in communicating research with non-scientists* was ranked as one of the lowest four items on their list by the majority of the students interviewed (n=11). These students provided a number of reasons as to why they attributed this civic science item a relatively low priority. Four students indicated that communicating with non-scientists was not important because an understanding of science was only important for scientists (n=1) and biotechnology may be too difficult for the public to understand (n=3). One student indicated he ranked science communication as one of the lowest of his responses because he felt that communication with non-scientists was only required when the public were "interested".

Two of the students gave the *Communication with non-scientists* item a relatively low level of importance because they felt science communication skills would be best offered as specialised course, rather than an integral component of the biotechnology degree program. Elena stated "Because that [skills in communicating research with non-scientists] is probably what you want to be basing a science communication course on". Joel stated "I think if that [skills in communicating research with non-scientists] is something you want to go into then you'll take a minor or a double degree in that."

The two students who did indicate that they felt skills in communicating research with non-scientists was a very important inclusion in their biotechnology degree program rated all of the items highly. When one of these students was prompted to indicate which item they would leave out if one were to be removed from their program of study she selected the *Skills in communicating with non-scientists* item.

DISCUSSION

Overall, the results presented in this study suggest that the current state of science communication training for the tertiary biotechnology students in the case study was limited. Very few of the students were aware of the communication skills training available to them and few indicated an intention to enrol. These results are consistent with a previous study examining the views of graduates of this biotechnology program (Author, 2008). This study found that very few of the students felt their undergraduate biotechnology degree program provided them with any form of science communication training, let alone training in how to engage audiences broader than their peers.

The importance of communication training for science students has been highlighted in Australia with the release of three reports assessing the relationship between the curriculum content in science degrees and employer and industry needs. All three reports investigated graduates' and employers' perceptions of the skills provided by undergraduate science degrees. The first report found that almost 90% of the 1245 graduates surveyed felt their degree training did not provide them with the level of communication skills required by their employer (Australian Council of the Deans of Science, 2001). The second report found that employers do not believe that a basic tertiary science education equips graduates with the essential generic skills required for the work place, particularly effective written and oral communication skills (Macquarie University, 2006).

The third report was commissioned to gauge if undergraduate biotechnology programs in Australia meet the demands of the Australian biotechnology industry (Gray & Franco, 2003). After reviewing 25 Australian universities, the authors concluded that there is a strong demand for graduates with communication skills. The report indicated that while generic communication skills are taught in the majority of biotechnology degrees (predominantly in the first and second years of study) these skills were taught with "varying degrees of efficacy" and recommended that "identification and dissemination of best practice" for teaching and oral written communication skills (p.4). However, while all three of these reports highlighted a need for improved generic communication skills training of science graduates, they did not assess the specific communication skills required of civic scientists.

In the present case study, the students enrolled in the undergraduate biotechnology program lack generic communication skills training and training for the communication skills required of civic scientists. A lack of formal training in both of these areas is likely to be a contributing factor to their limited understanding of science communication. Very few students acknowledged that science communication could involve both scientist-to-scientist communication *and* public engagement. It has been suggested that these forms of science communication are distinct and scientists need to be able to skilled at both (Aikenhead, 2001; Holten, 1978). Given that the only form of assessable science communication training the students are provided with in their degree program is formal report writing, it appears unlikely that the students are aware of the differences between these forms of communication and even less likely that they are skilled in both.

In the present study, none of the undergraduate biotechnology students in the case acknowledged that science communication could involve the mutual transfer of information between scientists and the public through open and equal dialogue, with some defining science communication as a one way transfer of knowledge from scientists to non-scientists. Known as the deficit approach to science communication (Clark & Illman, 2001), this approach assumes that non-scientists respond negatively to science and technology primarily because of a deficit in scientific knowledge, and understanding and acceptance of science can be achieved by the provision of sufficient scientific information to reduce this deficit.

Since the *Public Understanding of Science* report first sanctioned the deficit model two decades ago (Bodmer, 1985), science communicators' and policy-makers' approaches to science communication have advanced significantly. It is now felt that support for science cannot be achieved through improving the understanding of science alone. Science communication must attempt to build trust through dialogue in which participants must be aware of, respectful of, and responsive to the knowledge and concerns of all groups involved (Clark & Illman, 2001). Despite widespread support for scientists to revise their approach to science communication to encompass this revised form of public engagement, evidence suggests many scientists still see education of the public as the primary reason for science communication (Royal Society, 2006). The results of the present case study suggest the next generation of biotechnology graduates may also hold these outdated views.

While the biotechnology students' lack of understanding of science communication may be attributed to a lack of science communication training, the undergraduate students did agree that biotechnologists have a role to play in science communication and acknowledged that it is important for non-scientists to understand biotechnology. However, from the undergraduate students' interview responses it appears that many of these students equate an improved public understanding of science with improved acceptance of science. Furthermore they do rate public engagement highly in comparison to communicating with other possible audiences, such as fellow scientists, government and industry. This suggests that while these undergraduate biotechnology students are supportive of biotechnologists' role in science communication, they have little understanding of its function and perceive public engagement is a low priority in comparison to other forms of science communication.

In the *Role of Scientists in Public Debate* survey (Royal Society, 2006), scientists were asked a similar question to these undergraduate biotechnology students. When asked “How important do you feel it is that you personally, in your current post, directly engage with each of the following groups about your research?” 60% of the scientists afforded policy makers and 47 % afforded industry a high level of importance. In contrast much lower levels of importance were afforded to media representatives, non-government organisations, and the non-specialist public by many of the scientists. These results suggest that scientists see engaging with the public as something biotechnologists should be involved with in principle, but in practice afford this activity little value. The low numbers of scientists participating in public engagement is likely, in part, to reflect the low level of importance attributed to these activities. For scientists to engage with the public in a systematic way, it is likely that scientists will need to move beyond appreciating the need to participate in public engagement, to acknowledging the importance of their own participation in these activities and rating public engagement of equal importance as all other aspects of scientific practice. The results of the present study suggest this required attitudinal change may need to be explored as early as the undergraduate years.

While changes to science communication training of the undergraduate students in this case study is clearly required, these changes will need to take into account the value these students place on science communication training. The results of this study suggest that undergraduate students view this training as one of the least important components of their degree programs. From the follow-up interviews it was evident that some undergraduate students ranked the communication with non-scientists item as a relatively unimportant component of their training because they did not value public engagement. Others felt science communication training was only required for students who intended to become specialist science communicators, not those who intended to pursue careers as research scientists. These views of science communication and science communication training may also be shared with undergraduates enrolled in other science programs, as the results obtained for the biotechnology students in this case study were comparable to the results obtained for the other science students surveyed. Overall, these results suggest that if science communication training is offered at the tertiary level as an elective unit, it will need to be seen as valuable by the students if they are to enrol.

Given that many of the undergraduate biotechnology students do not value science communication training, the provision of an elective science communication unit may only attract those students with a pre-existing interest in science communication. A number of the students suggested that science communication training would be better offered as a specialist course for students interested in pursuing science communication careers. Errington and coworkers (Errington, Bryant, & Gore, 2001), however, suggest that offering postgraduate programs in science communication is like “preaching to the converted” as the graduates in the program already have a keen interest in science communication, generally have quite good communication skills, and generally find employment within the science communication industry. If science communication training does not reach science graduates who remain in mainstream science research, their civic science skills may never be fully developed and public engagement may not be improved.

Moving science communication training from being an optional elective to a compulsory component of biotechnology education will ensure that all undergraduate biotechnology students are taught how to communicate with the public. Lessons in how science communication may be integrated into the biotechnology curriculum may be learnt from the analysis of biotechnology programs that have included ethics studies into the curriculum (Stern & Elliot, 1997). In recent years, ethics has become part of many tertiary biotechnology curricula in response to calls for the inclusion of courses in research and professional ethics in tertiary science education (Lysaght, Rosenberger, & Kerridge, 2006). While there is significant variation in the extent and content of ethics education provided to students in different institutions, there is gradual recognition of the importance of incorporating ethics into biotechnology degrees. Employers support the provision of ethics education and undergraduate students generally regard ethics education to be important.

Conclusion

This study of a biotechnology program indicates that biotechnology students may graduate from their degree program with a limited understanding of science communication and little regard for science communication training. There are several implications of these findings for the biotechnology curriculum planners if these programs are to generate graduates that are willing and able civic scientists.

Biotechnology programs will need to redress students' limited understanding of science communication through the provision of training in this area. However, the form this training takes will need to take into account the value students place on communicating with non-scientists and how receptive they are to learning these skills.

Further research may be directed towards examining lecturers' views of science communication and science communication training. Understanding how lecturers feel this training would fit within the biotechnology curriculum and what barriers need to be overcome to allow for the delivery of this training, may be used to support the introduction of this material. Through these advances in understanding, it is hoped that the science communication training for undergraduate biotechnology students may be improved. This training should aim for to develop a cohort of graduates who are skilled in communicating with their fellow scientists and equally skilled and willing civic scientists.

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REFERENCES

Aikenhead, G. S. (2001). Science communication: a cross cultural event. In S. M. Stocklmayer, M. G. Gore & C. Bryant (Eds.), *Science communication in theory and practice*. Dordrecht: Kluwer Academic.

Allum, N., Sturgis, P., Tabourazi, D., & Brunton-Smith, I. (2008). Science knowledge and attitudes across cultures: a meta-analysis. *Public Understanding of Science, 17*, 35-54.

American Association for the Advancement of Science. (2007). *Center for Public Engagement with Science and Society. Overview.* [Electronic Version]. Retrieved 12 October 2009 from http://www.aaas.org/programs/centers/pe/.

Australian Council for the Deans of Science. (2001). *What did you do with your science degree?* Melbourne: Centre for the Study of Higher Education, University of Melbourne.

Author (2008).

Bodmer, W. (1985). *The public understanding of science*. London: Royal Society.

Boulter, D. (1999) Public perception of science and associated general issues for the scientist. *Phytochemistry*, *50*, 1-7.

Carroll, S. (2006). Welcome. *Australasian Biotechnology*, *16*(1), 4.

Clark, F., & Illman, D. L. (2001). Dimensions of civic science. *Science Communication, 23*(1), 5-27.

Cresswell, J. W. & Plano Clark, V. L. (2007). *Designing and conducting mixed methods research*. Thousand Oaks, CA: Sage.

Errington, S., Bryant, C., & Gore, M. G. (2001, 1-3 February, 2001). *The evolution of science communication courses: Training scientists to communicate.* Paper presented at the 6th International Conference on Public Communication and Strategy. Trends in Science Communication Today - Bridging the Gap Between Theory and Practice, Cern, Geneva.

Eureka Strategic Research. (2005). *Public awareness research 2005. Overview*. Canberra: Biotechnology Australia. Retrieved 12 October 2009 from http://www.biotechnology.gov.au/index.cfm?event=object.showContent&objectID=D8E567B4-EEF9-74DC-BE8C7F439D9DF702

Eureka Strategic Research. (2007). *Community Attitudes to Biotechnology Summary Report. Eureka Project 4001*. Canberra: Biotechnology Australia. [Electronic Version]. Retrieved 12 October 2009 from http://www.biotechnology.gov.au/assets/documents/bainternet/Biotechnologysummaryreport20070720190245.pdf

Federation of Australian Scientific and Technological Societies. (1999). *Biotechnology in Australia. Occasional Paper Number 1*. [Electronic Version]. Retrieved 12 October 2009 from http://www.fasts.org/images/occasional-papers/occ_paper_one.pdf

Friedman, H. H., & Amoo, T. (1999). Rating the rating scales. *Journal of Marketing Management*, *9*(3), 114-123.

Gaskell, G., Allum, N., Bauer, B., Durant, J., Allansdottir, A., Bonfadelli, H., et al. (2000). Biotechnology and the European public. *Nature Biotechnology, 18*, 939-942.

Gray, P., & Franco, C. (2003). *Australian Universities Teaching Committee Review of Biotechnology*. Canberra: Commonwealth of Australia Department of Education, Science and Technology.

Gregory, J. (2003). Understanding 'science and the public'. *Journal of Commercial Biotechnology, 10*(2), 131.

Guba. E.G. & Lincoln. Y.S. (1989). *Fourth generation evaluation*. Newbury Park, CA: Sage.

Harrison, D. A., & McLaughlin, M. E. (1993). Cognitive processes in self-report responses: test of item context effects in work attitude measures. *Journal of Applied Psychology, 78*, 129-140.

Hitchcock, G., & Hughes, D. (1995). *Research and the teacher*. London: Routledge.

Holten, G. (1978). *The scientific imagination. Case studies.* Cambridge: Cambridge University Press.

Hornig Priest, S. H. (2001). Misplaced faith: Communication variables as predictors of encouragement for biotechnology development. *Science Communication, 23*(2), 97-110.

House of Lords. (2000). *Science and society. Select Committee on Science and Technology Third Report.* London: Her Majesty's Stationary Office. [Electronic Version]. Retrieved 12 October 2009 from http://www.publications.parliament.uk/pa/ld199900/ldselect/ldsctech/38/3801.htm

Huck, S. W., & Cormier, W. H. (1996). *Reading statistics and research*. New York, NY: HarperCollins.

Lane, N. F. (1997). An open letter to scientists and engineers: Let's get the word out together about why science matters. Retrieved December, 2006, from www.nsf.gov/od/lpa/news/media/nlaaultr.htm

Lavelle, A. (2006). Federal budget improves future for Australian biotechnology. *Australasian Biotechnology, 16*(1), 20-21.

Lysaght, T., Rosenberger, P. J., & Kerridge, I. (2006). Australian undergraduate biotechnology student attitudes towards the teaching of ethics. *International Journal of Science Education, PrEview*, 1-15.

Macquarie University. (2006). *Science, engineering and technology study*. Sydney: Macquarie University.

Miller, G. A. (1956). The magical number seven, plus or minus two. Some limits on our capacity for processing information. *Psychological review, 63*, 81-97.

Millward Brown. (2001). *Biotechnology Public awareness survey*. Canberra: Biotechnology Australia. [Electronic Version]. Retrieved 12 October 2009 from http://www.biopoliticaltimes.org/downloads/200107_Biotechnology_Australia.pdf

Millward Brown. (2003). *Biotechnology Public awareness survey*. Canberra: Biotechnology Australia. [Electronic Version]. Retrieved 12 October 2009 from http://adl.brs.gov.au/brsShop/data/ryan09july.pdf

National Science Board. (2000). *Science and engineering indicators - 2000*. Arlington, VA: National Science Foundation.

National Science Foundation/Department of Commerce. (2002). *Converging technologies for improving human performance. Nanotechnology, biotechnology, information technology and cognitive science.* Arlington, Virginia: National Science Foundation.

Oppenheim, A. N. (2001). *Questionnaire design, interviewing and attitude measurement*. London: Continuum.

Organisation for Economic Cooperation and Development (OECD). (2005). OECD Science, Technology and Industry Scoreboard 2005 [Electronic Version]. Retrieved 12 October 2009 http://www.oecd.org/dataoecd/59/52/35465901.pdf

Priest, S. H. (2000). US public opinion divided over biotechnology. *Nature Biotechnology, 18*(939-942).

QSR International. (2002). Using NVivo in qualitative research. Software manual - Edition 3. Melbourne, VIC: QSR International.

Royal Society. (2005). *Connecting science: what we know and what we don't know about science in society*. London: The Royal Society.

Royal Society. (2006). Survey of factors affecting science communication by scientists and engineers [Electronic Version]. Retrieved 12 October, 2009 from www.royalsoc.ac.uk/page.asp?id=3180&printer=1.

SAS Institute Inc. Statview (Version 5). Cary, NC: SAS Institute Inc.

Shortland, M., & Gregory, J. (1991). *Communicating science. A handbook.* New York: Longman.

Smith, J. E. (2001). Public perception of biotechnology. In C. Ratledge & B. Kristiansen (Eds.), *Basic Biotechnology. Second Edition.* (pp. 3-16). Cambridge: Cambridge University Press.

Stake, R. E. (2000). Case studies. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (Vol. 2, pp. 435-454). Thousand Oaks, CA: Sage.

Stern, J. E., & Elliot, D. (1997). *The ethics of scientific research. A guidebook for course development*. Buffalo, NY: University Press of New England.

Stocklmayer, S. M., Gore, M. G., & Bryant, C. (2001). Introduction and overview. In S. M. Stocklmayer, M. G. Gore & C. Bryant (Eds.), *Science communication in theory and practice* (Vol. 14). Dordrecht: Kluwer Academic Publishers.

Triese, D., & Weigold, M. F. (2002) Advancing science communication. *Science Communication, 23*(3), 310-322.

Wellcome Trust/MORI. (2000). *The role of scientists in public debate*. London: Wellcome Trust. [Electronic Version]. Retrieved 12 October 2009 http://www.wellcome.ac.uk/stellent/groups/corporatesite/@msh_peda/documents/web_document/wtd003425.pdf

Whitmarsh, L., & Kean, S. (2005). *Connecting science. What we know and what we don't know about science in society.* London: British Association for the Advancement of Science. [Electronic Version]. Retrieved 12 October 2009 http://www.britishscienceassociation.org/NR/rdonlyres/CE852B1D-7699-43A1-91C4-382DB5877D45/0/ConnectingScience_review.pdf

Yann Campbell Hoare Wheeler. (1999). *Public Attitudes to Biotechnology*. Canberra: Biotechnology Australia. [Electronic Version]. Retrieved 12 October 2009 http://www.biotechnology.gov.au/index.cfm?event=object.showContent&objectID=FC7F7DBE-BCD6-81AC-135CD90389558AFC

Yin, R. K. (2003). *Case study research. Design and Methods.* Thousand Oaks, CA: Sage.

Appendix: Questionnaire items

Closed questions:

1. What program are you enrolled in? Biotechnology / Other
2. Have you completed the *Science Communication* unit*?* Yes / No
3. Do you plan to enrol in the *Science Communication* unit*?* Yes / No

Open questions:

4. Have you have received any training in how to communicate the *technical aspects* of biotechnology research with the non-scientists, at any stage of your degree program? If Yes, which units this training was provided in and describe the type of training provided.
5. Have you have received any training in how to communicate the *social and ethical implications* of biotechnology research with the non-scientists, at any stage of your degree program? If Yes, which units this training was provided in and describe the type of training provided.

Rating Scale questions:

6. How important do you think it is that the following items are included in the undergraduate biotechnology curriculum? A broad knowledge of general scientific facts and theories / Skills in communicating research with other scientists / Business and marketing skills / Technical skills (eg. lab work) / Data analysis skills (eg. statistical analysis) / An understanding of intellectual property and patenting issues / An understanding of animal ethics regulations

and related issues / Skills in communicating research with non-scientists / An understanding of human ethics regulations and related issues / An appreciation of what constitutes scientific misconduct / Knowledge of the specific facts and theories related to biotechnology / An awareness of the public's perception of the risks associated with research and research outcomes (Unimportant to Very Important; 12 items).

7. How important do you think it is that the non-scientists understand the technical aspects of biotechnology research? (Unimportant to Very important; 1 item).
8. How important do you think it is that the non-scientists understand the social and ethical implications of biotechnology research? (Unimportant to Very important; 1 item)
9. How responsible should the following groups be for communicating the *technical aspects* of biotechnology research with non-scientists? Government / Journalists / Professional Science Communicators / Campaigning Groups (e.g. Greenpeace) / Biotechnologists (Not Responsible to Very Responsible; 6 items)
10. How responsible should the following groups be for communicating the *social and ethical implications* of biotechnology research with non-scientists? Government / Journalists / Professional Science Communicators / Campaigning Groups (e.g. Greenpeace) / Biotechnologists (Not Responsible to Very responsible; 6 items)
11. How strongly do you agree or disagree with the following statements? Biotechnologists have a responsibility to communicate the technical aspects

of their research with the non-scientists.(Strongly Disagree to Strongly Agree; 1 item)

12. Biotechnologists have a responsibility to communicate the ethical and social implications of their research with non-scientists.(Strongly Disagree to Strongly Agree; 1 item)
13. Biotechnologists have a responsibility to communicate their research and its implications with non-scientists, but only after peer review. .(Strongly Disagree to Strongly Agree; 1 item)
14. Science communication activities may impact on non-scientists in a number of ways. Indicate how you would rate the success of a science communication activity if it resulted in the following *responses by non-scientists?* Improved awareness of biotechnological products and processes / Improved understanding of biotechnological products and processes / Greater debate about biotechnological products and processes / Greater acceptance of biotechnological products and processes. (Failure to Success; 4 items)
15. How would you rate the importance of communicating the *technical aspects* of biotechnology research with the following groups? Biotechnologists / Scientists other than biotechnologists / Non-specialist public / Managers of biotechnology industries / Journalists / Government (Unimportant to Very Important; 6 items).
16. How would you rate the importance of communicating the *social and ethical implications* of biotechnology research with the following groups? Biotechnologists / Scientists other than biotechnologists / Non-specialist

public / Managers of biotechnology industries / Journalists / Government (Unimportant to Very Important; 6 items).

Additional open question:

17. What does the term ‘science communication’ mean to you?

Table 1: *Undergraduate Students Administered the Short Questionnaire by Program of Enrolment*

Year of enrolment	Biotechnology Program *n*	Non-Biotechnology Programs *n*	Total *n*
1st Year	17	219	236
Female	6	153	
Male	11	66	
2nd Year	23	29	52
Female	9	24	
Male	14	5	
3rd Year	29	26	55
Female	13	19	
Male	16	7	
Total	69	274	343

Figure 1: Second year undergraduate biotechnology student (n=23) responses to the questions "How responsible should the following groups be for communicating the technical aspects of biotechnology research to non-scientists" (red box plots) and "How responsible should the following groups be for communicating the social and ethical implications of biotechnology research to non-scientists" (blue box plots). The items are arranged in the order of importance attributed to the technical research item.

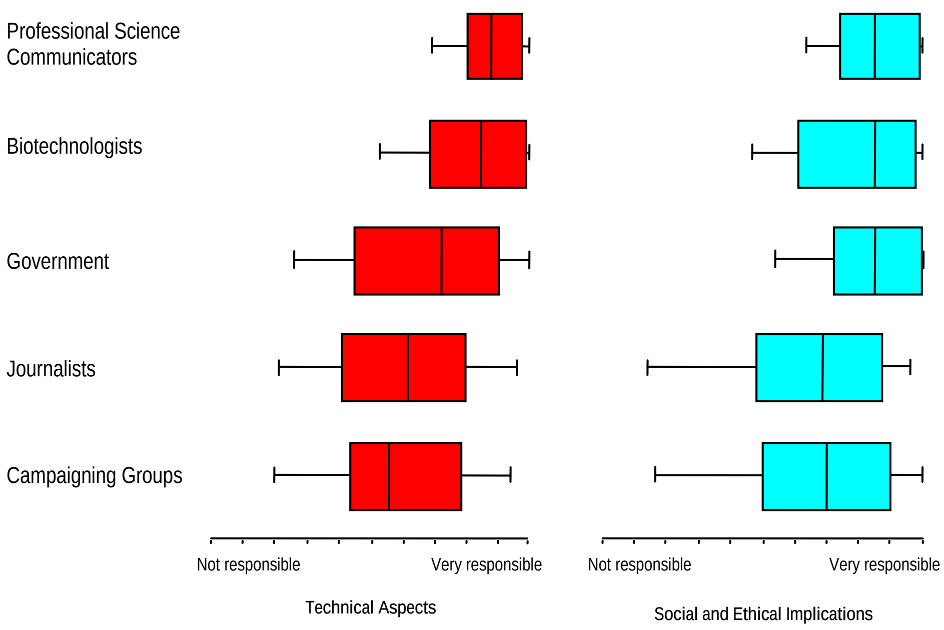

Figure 2: Second year undergraduate biotechnology student (n=23) responses to the questions “How would you rate the importance of communicating the technical aspects of biotechnology research to the following groups?” (red box plots) and “How would you rate the importance of communicating the social and ethical implications of biotechnology research to the following groups?” (blue box plots). The items are arranged in the order of importance attributed to the technical research item.

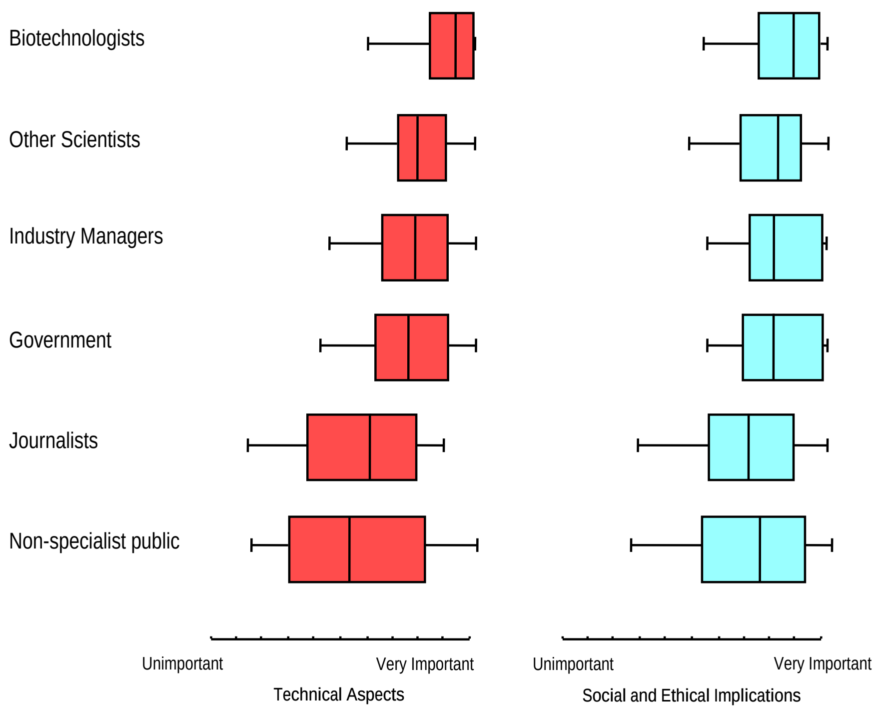

Figure 3: Undergraduate science student ranking of the importance of 12 curriculum items according to degree program of enrolment. The biotechnology students' (n=69) responses to the question *How important do you think it is that the following items are included in the undergraduate biotechnology curriculum?* are represented by the dark blue box plots. The responses of the science students' (n=274) enrolled in non-biotechnology degree programs are represented by the light blue box plots. The items are arranged in the order of importance attributed by the biotechnology students. Adjacent items that have significantly different mean scores for the biotechnology students are separated by a dashed line.