Promotion of biotechnology amongst students by university departments in South Africa

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Abstract
University departments (including schools and centres) with a direct or indirect link to biotechnology were identified. Representatives at these entities were surveyed to establish what measures South African universities are undertaking to promote biotechnology amongst students. Of the 168 departments identified, 55 submitted usable questionnaires. Four broad types of initiatives were identified: (1) facilitation of funding from the National Research Foundation, (2) facilitation of relevance, (3) facilitation of biotech industry networks, and (4) facilitation of biotech industry funding. Initiatives that the departments most frequently engage in pertain to the traditional role of universities, namely to ensure public funding for students and to academically prepare undergraduate biotechnology students to successfully complete postgraduate studies. Initiatives that link students to the biotechnology sector more directly and dynamically (through various forms of university-industry interaction) are less frequently practiced. The respondents also discussed a number of additional actions that are taken by their departments to facilitate the entrance of students into the biotechnology sector, as well as insights and suggestions as to how universities can promote biotechnology amongst students. The tension between ‘biotechnology as a discipline’ and ‘biotechnology as an interdisciplinary tool’ was raised and is highlighted as a subject of concern.

INTRODUCTION
There are numerous potential benefits that South Africa can accrue from the successful commercialisation of biotechnology research. These include financial gains, more effective and in many instances cheaper pharmaceuticals and medical procedures, a higher yielding agricultural output that consists of enhanced nutritional value, and solutions to environmental crises. South Africa is also well positioned to conduct biotechnology research owing to its large biodiversity, its proximity to major infectious diseases, and diverse human genetic pool. It is therefore not surprising that the South African government adopted a National Biotechnology Strategy in 2001 to advance progress in this field (DST 2001). Central to this Strategy has been the establishment
of Biotechnological Regional Innovation Centres (BRICs), technology incubators for biotechnology, and numerous other infrastructural and legal support initiatives. Recently the government also published a 10-year innovation plan for 2008–2018, which formally set the objective for South Africa to become one of the top 10 nations in the world in terms of the pharmaceutical, nutraceutical, flavour, fragrance, and biopesticide industries (DST 2007a).

The successful implementation of the aforementioned strategy and the subsequent development of a prosperous biotechnology industry necessitates the development of relevant expertise and the procurement and mobilization of relevant talent for local industry. Currently indications are that there exists a significant shortage of appropriate expertise. The 2003 National Biotech Survey noted a ‘scarcity of R&D personnel, particularly at the MSc and PhD levels’ (Mulder and Henschel 2003, 3). Furthermore, over half of the companies and over 80 per cent of the research stakeholders participating in the National Biotech Survey reported a shortage in the availability of skilled scientists. The 2007 National Biotechnology Audit also emphasized the shortfall in appropriate expertise (DST 2007b). More recently, in a report investigating the chemical advances of biotechnology research, Jarvis (2009) concluded that the South African biotechnology industry is fragmented and lacks critical mass as relevant expertise commonly rests with single scientists.

Pouris and Pouris (2009) investigated the institutional affiliations of South African scientists who publish in biotechnology. Using the ISI Web of Science (WoS) databases they conclude that the most prolific producers of biotechnology, who published research papers between 1995 and 2007, were from the universities of Cape Town (22%), Stellenbosch (18%), Witwatersrand (16%), Pretoria (11%) and KwaZulu-Natal (8%). Research councils contributed less than 3 per cent. Pouris and Pouris noted that South Africa produces substantially fewer biotechnology related publications than other countries, many of which have smaller populations. The number of research articles in biotechnology, when calculated as a percentage of the total publications output for a country, gives an indication of the research emphasis in this field. To meet the comparative norms of other countries South Africa will have to double its output in the subject categories of cell biology, biophysics, developmental biology, and biochemistry and molecular biology (Pouris and Pouris 2009, 37).

Recently, the Organisation for Economic Co-operation and Development (OECD) started to engage in the articulation of a policy agenda for the global bio-economy, as it is believed that a substantial component of the world economic output eventually will be accounted for by the development and use of biological materials. Of particular importance is the observation by the OECD that the future bio-economy, being global, will increasingly also incorporate trained scientists in developing countries (OECD 2009):

Rapid income and population growth will ensure that the main markets for biotechnology in agriculture and industry will be in developing countries .... Rising levels of educational achievement across the developing world, particularly at the
tertiary level, will create centres of biotechnology research that can address some of the problems that are likely to develop in these countries, including a growing need for low carbon energy, clean water, and high-yield agricultural crops that can tolerate drought, heat and other stresses. (OECD 2009, 9).

It is against this backdrop of an increased awareness of the importance of biotechnology training at tertiary level that the current study was introduced. The objective is to determine what measures South African universities are undertaking to promote biotechnology amongst their students. Specifically, a survey was conducted to determine the nature of the activities employed by university departments, schools and centres (offering biotechnology related training) to encourage students to pursue research and careers in biotechnology. The study formed part of a larger Biotechnology Human Capital Needs Analysis that was commissioned by the South African Agency for Science and Technology Advancement (SAASTA), a business unit of the National Research Foundation (NRF).

However, before presenting the methodology and results of the study, a clarification of the concept of biotechnology is required. This study follows the definitions of biotechnology from the OECD (Van Beuzekom and Arundel 2006), which include both a broad single definition and a more specific list-based definition of biological techniques:

Single definition:
The application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services.

List-based definition of techniques:


b. **Proteins and other molecules**: Sequencing/synthesis/engineering of proteins and peptides (including large molecule hormones); improved delivery methods for large molecule drugs; proteomics, protein isolation and purification, signalling, identification of cell receptors.

c. **Cell and tissue culture and engineering**: Cell/tissue culture, tissue engineering (including tissue scaffolds and biomedical engineering), cellular fusion, vaccine/immune stimulants, embryo manipulation.

d. **Process biotechnology techniques**: Fermentation using bioreactors, bioprocessing, bioleaching, biopulping, biobleaching, biodesulphurisation, bioremediation, biofiltration and phytoremediation.

e. **Gene and RNA vectors**: Gene therapy, viral vectors.

f. **Bioinformatics**: Construction of databases on genomes, protein sequences; modelling complex biological processes, including systems biology.
g. **Nanobiotechnology**: Applies the tools and processes of nano/microfabrication to build devices for studying bio systems and applications in drug delivery, diagnostics etc.

**METHODOLOGY**

Given the interdisciplinary nature of biotechnology, a number of methodological approaches were implemented in an attempt to identify university departments, schools and centres that offer training programmes that are either directly or indirectly linked to the field.

a. Firstly, we used the information contained in an unpublished report on biotechnology research offerings at South African universities, compiled by the National Research Foundation (NRF) (Claassen-Veldsman 2009).

b. Secondly, we used bibliometric procedures to identify university researchers who publish in the field of biotechnology. All WoS research papers published by university researchers in biotechnology during the period 2006–2008 were systematically identified on the basis of the subject classification of the journals in which the papers appear. We followed the suggestion by Molatudi and Pouris (2006) who considered the disciplines of molecular biology, genetics, and microbiology as the core scientific disciplines contributing to exploitable biotechnology based results. In our study this resulted in four subject categories in the WoS classification being used to identify biotechnology and related papers: (1) biochemistry and molecular biology; (2) biotechnology and applied microbiology; (3) genetics and heredity; and (4) microbiology. Once the relevant papers were extracted, the departmental affiliations of the South African authors (as specified in the author address field) were noted and the websites of the identified departments consulted to search for biotechnology related training programmes.

c. Thirdly, we identified university students who completed a postgraduate thesis or dissertation in the field of biotechnology and inspected the programmes listed for those theses or dissertations. Here we consulted the Union Catalogue of Theses and Dissertations (UCTD), specifically with regard to theses or dissertations classified as belonging to biotechnology, based on UCTD search criteria.

d. Lastly, a few additional biotechnology-related programmes were identified on the basis of relevant funding information. Specifically, we received from the NRF the names, institutional affiliations and project titles of applicants who responded to the call in 2009 for funding proposals in the Bioinformatics and Functional Genomics Programme.

The combined methodological approach resulted in a working database of 168 university departments/schools/centres (hereafter referred to as only ‘departments’) that have a direct or indirect link to biotechnology and which, potentially, also
of biotechnology related training at various levels and to various degrees. Once the database was compiled the surveying of the heads of departments (or senior academics within the departments) could begin. The contact detail of the relevant person in each department was obtained by searching the internet and, where that strategy failed, by phoning the department. Eventually contact particulars were obtained for 154 departments. The targeted individuals in these departments received an email that specified the research objective and asked for an online questionnaire to be completed.

Other than requesting select demographic information (university, department and position), the questionnaire also asked for the details of three training programmes most relevant to a career in biotechnology, as well as the domain classification of the training programmes (i.e. agriculture, animal health, human health or industrial and environmental biotechnology), and ratings of the extent to which certain biotechnology promotional activities are being applied within the department. Additional promotional activities could also be specified. Respondents’ insights and suggestions as to what universities can do to promote biotechnology amongst students were also solicited.

Altogether 55 (36%) valid questionnaires were received. In addition, 5 per cent of emails failed without any alternatives being available, 15 per cent of targeted individuals replied that the questionnaire did not apply to them as they do not offer biotechnology training, and 44 per cent of targeted individuals did not respond at all (although the emails were delivered). The results presented are based on the 55 questionnaires received.

RESULTS

Demographics

The majority of departments in the survey (42 of the 55) are located at traditional universities, with another 7 at universities of technology and 6 at comprehensive universities. Respectively 28 and 9 of the departments offer biotechnology training only at undergraduate or postgraduate level, and 15 departments do so at both undergraduate and postgraduate level. Three departments did not specify the level of their training programmes.

Marked numbers of departmental representatives listed industrial and environmental biotechnology (34 respondents) and agricultural biotechnology (30 respondents) as their programme domains. Respectively 25 and 13 respondents specified human health and animal health as the domains of their biotechnology training. However, these four domains are not mutually exclusive because respondents were allowed to specify more than one.

The departments were also classified as either directly involved in biotechnology training (so-called ‘core biotechnology’ department) or as having some relation to biotechnology training. The presence of any of the following two elements
determined whether a department was classified in the core biotechnology group: (1) the word ‘biotechnology’ appeared in the name of the department; and/or (2) the word ‘biotechnology’ appeared in the name of any of the training programmes offered. These criteria resulted in 16 departments being classified as having a direct link with biotechnology and 39 as being related to biotechnology in some other way.

**Activities that facilitate the entrance of students into the biotechnology sector**

The respondents were presented with 12 activities that potentially could facilitate the entrance of students into the biotechnology sector, and had to rate each in terms of the extent to which their department engages in that activity (‘we always do so’; ‘we sometimes do so’; ‘we never or almost never do so’). The responses are summarised in Table 1. An inspection of the three activities with the highest occurrence (i.e. items where more than 50% of respondents said that ‘we always do so’) reveals that these activities relate to the traditional role of universities, namely to ensure public funding for students (from the NRF) and to academically prepare undergraduate students to successfully complete postgraduate studies. The next two activities with relatively high occurrences (i.e. where 46% and 42% of respondents said that ‘we always do so’) also underscore the traditional role of universities because the focus is on knowledge dissemination at conferences and (passively) providing information to students about job market demands. Activities that link students to the Biotechnology sector more directly and dynamically (through various forms of university-industry interaction) are less frequently practiced (less than 30% of respondents saying that ‘we always do so’).

**Table 1: Actions taken by departments to facilitate the entrance of students into the biotechnology sector**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Rating</th>
<th>Number of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inform students of the availability of NRF funding in a biotechnology-related domain</td>
<td>58 29 13</td>
<td>55</td>
</tr>
<tr>
<td>Assist students to apply for NRF funding in a biotechnology-related domain</td>
<td>55 36 9</td>
<td>55</td>
</tr>
<tr>
<td>Ensure that the undergraduate courses adequately prepare students for postgraduate biotechnology work</td>
<td>53 32 15</td>
<td>53</td>
</tr>
<tr>
<td>Provide students with relevant career information in biotechnology</td>
<td>46 38 16</td>
<td>55</td>
</tr>
</tbody>
</table>
Facilitate the participation by students at conferences where the private and public biotechnology sector is well-represented | 42 | 33 | 25 | 55

Supervise or co-supervise the work of postgraduate students with scientists from biotechnology-related industries | 26 | 49 | 25 | 55

Expose students to representatives from biotechnology-related industries who participate in teaching programme(s) | 22 | 45 | 33 | 55

Link students to the biotechnology networks of staff | 22 | 45 | 33 | 55

Invite representatives from biotechnology-related industries to forums where postgraduate research is presented | 22 | 44 | 34 | 55

Expose students to representatives from biotechnology-related industries who participate in research programme(s) | 21 | 62 | 17 | 53

Assist students to obtain funding from biotechnology-related industries | 17 | 54 | 29 | 54

Arrange for students to do practical work at biotechnology-related industries to supplement their training | 13 | 34 | 53 | 55

Moreover, it was considered worthwhile to identify the underlying dimensions (components) of the 12 items, based on their inter-correlations. For this reason a principal component analysis (PCA) was performed. First, however, the inter-correlations of the items were examined to determine their appropriateness for inclusion in the PCA. Specific statistics, such as the measure of sampling adequacy (MSA), assisted in determining which items should be included in the PCA. On the basis of this preliminary examination, all 12 items were deemed appropriate for inclusion in the PCA. A conceptually clear solution was obtained by specifying four components to be extracted, and performing an orthogonal (VARIMAX) rotation. The four components together explain 72 per cent of the original variability in the set of items, and each item has a loading above 0.50 on the component that it represents, which make all loadings both practically and statistically significant.
Table 2: The four components, their reliabilities, and labels assigned on the basis of items that load significantly on each component

<table>
<thead>
<tr>
<th>Components</th>
<th>Items loading on each component</th>
<th>Labels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component 1 (Cronbach’s Alpha = 0.893)</td>
<td>Expose students to representatives from biotechnology-related industries who participate in research programmes</td>
<td>Facilitate biotech industry networks</td>
</tr>
<tr>
<td></td>
<td>Expose students to representatives from biotechnology-related industries who participate in teaching programmes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Link students to the biotechnology networks of staff</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Invite representatives from biotechnology-related industries to forums where postgraduate research is presented</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Facilitate the participation by students at conferences where the private and public biotechnology sector is well-represented</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Supervise or co-supervise the work of postgraduate students with scientists from biotechnology-related industries</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Arrange for students to do practical work at biotechnology-related industries to supplement their training</td>
<td></td>
</tr>
<tr>
<td>Component 2 (Cronbach’s Alpha = 0.842)</td>
<td>Assist students to apply for NRF funding in a biotechnology-related domain</td>
<td>Facilitate NRF funding</td>
</tr>
<tr>
<td></td>
<td>Inform students of the availability of NRF funding in a biotechnology-related domain</td>
<td></td>
</tr>
<tr>
<td>Component 3 (Cronbach’s Alpha = 0.755)</td>
<td>Ensure that the undergraduate courses adequately prepare students for postgraduate biotechnology work</td>
<td>Facilitate relevance</td>
</tr>
<tr>
<td></td>
<td>Provide students with relevant career information in biotechnology</td>
<td></td>
</tr>
<tr>
<td>Component 4</td>
<td>Assist students to obtain funding from biotechnology-related industries</td>
<td>Facilitate biotech industry funding</td>
</tr>
</tbody>
</table>

Cronbach’s Alpha measures the internal consistency reliability of a component that consists of two or more items. A value of at least 0.70 is normally regarded as the appropriate cut-off point for a construct or component to be reliable.

The labels assigned to the components, based on an inspection of the contents of the individual items loading on a component, are as follows (see also Table 2):

a. One component was labeled the facilitation of biotech industry networks because each of the seven items loading on this component highlights a particular university-industry linking mechanism. Thus, the facilitation of biotech industry networks can be interpreted as one initiative to promote the entrance of students from biotechnology related training programmes into biotechnology careers.

b. A second component is built around NRF funding, which justifies the obvious label of facilitation of NRF funding. Public funding, as a biotechnology support initiative, enables students to devote more attention to their studies and (hopefully) also to complete their studies within the specified time-to-degree period, thereby facilitating and accelerating their entrance into biotechnology careers.

c. The third component is interesting because of an apparent lack of association between the two items that comprise this component. However, at closer
inspection it is clear that the two items are significantly connected. The initiative that underlies this component is the facilitation of relevance, which is achieved through the alignment of undergraduate courses with postgraduate course demands and the alignment of student supply and expectations with industry demands (through the provision of relevant career information). The end result of these two (interrelated) sets of alignments is training that can be considered relevant to a career in biotechnology.

d. The last component comprises a single item and the content of the item makes its labeling self-explanatory: the facilitation of biotech industry funding.

**Table 3: Mean scores (out of 10) on the four biotechnology support initiatives (components), by demographic variables**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Facilitate NRF funding</th>
<th>Facilitate relevance</th>
<th>Facilitate biotech industry networks</th>
<th>Facilitate biotech industry funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>All respondents</td>
<td>7.3</td>
<td>6.5</td>
<td>4.6</td>
<td>4.3</td>
</tr>
<tr>
<td>University classification</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Universities (n=42)</td>
<td>7.2</td>
<td>6.0</td>
<td>4.2</td>
<td>3.8</td>
</tr>
<tr>
<td>Universities of technology (n=7)</td>
<td>6.4</td>
<td>8.6</td>
<td>6.4</td>
<td>5.7</td>
</tr>
<tr>
<td>Comprehensive universities (n=6)</td>
<td>8.8</td>
<td>7.9</td>
<td>5.0</td>
<td>5.8</td>
</tr>
<tr>
<td>Statistical significant difference (p&lt;0.05) according to Kruskal-Wallis test?</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Level of programme</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Undergraduate (n=28)</td>
<td>6.8</td>
<td>5.7</td>
<td>4.0</td>
<td>4.1</td>
</tr>
<tr>
<td>Postgraduate (n=9)</td>
<td>8.1</td>
<td>6.1</td>
<td>4.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Both (n=15)</td>
<td>7.8</td>
<td>8.8</td>
<td>6.1</td>
<td>4.7</td>
</tr>
<tr>
<td>Statistical significant difference (p&lt;0.05) according to Kruskal-Wallis test?</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Core biotechnology versus biotechnology related</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Core biotech (n=16)</td>
<td>8.9</td>
<td>8.3</td>
<td>6.7</td>
<td>5.3</td>
</tr>
<tr>
<td>Biotech related (n=39)</td>
<td>6.6</td>
<td>5.8</td>
<td>3.7</td>
<td>3.8</td>
</tr>
<tr>
<td>Statistical significant difference (p&lt;0.05) according to Mann-Whitney U test?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Domain</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biotechnology in agriculture (n=30)</td>
<td>7.2</td>
<td>7.2</td>
<td>5.3</td>
<td>5.5</td>
</tr>
<tr>
<td>Biotechnology in animal health (n=13)</td>
<td>8.1</td>
<td>7.5</td>
<td>4.7</td>
<td>5.4</td>
</tr>
<tr>
<td>Biotechnology in human health (n=25)</td>
<td>7.9</td>
<td>7.4</td>
<td>4.2</td>
<td>4.4</td>
</tr>
<tr>
<td>Industrial and environmental biotechnology (n=34)</td>
<td>8.2</td>
<td>7.1</td>
<td>5.2</td>
<td>4.6</td>
</tr>
</tbody>
</table>

No statistical-significance testing was performed for ‘domain’ because the four foci are not mutually exclusive.
Next, a total score was computed for each component by summing the scores of individual items. However, since each component comprises a different number of items the maximum total score across the four components also differed, which required standardisation of the total scores. This was achieved by expressing each component’s total score as a value that ranges between 0 (biotechnology support initiative is absent) and 10 (biotechnology support initiative is significantly present).

Table 3 shows the mean scores for each of the four components. On average, the respondents scored highest on the component that relates to facilitation of NRF funding (mean score of 7.3 out of 10). In other words, conveying information about available NRF funding to students, as well as helping students to access that funding, appears to be the most prominent biotechnology promotion initiative. A second component, the facilitation of relevance, also has an above average presence in the study (mean score of 6.5). The remaining components both have below-average scores (4.6 and 4.3 out of 10), meaning that departments are less likely to promote biotechnology as a career (amongst students) through the facilitation of industry networks or industry funding.

Moreover, the facilitation of relevance (as an initiative) is particularly high amongst universities of technology (mean score of 8.6 out of 10) and comprehensive universities (mean score of 7.9). The common factor is that these two university types incorporate the former technikons, which were largely oriented towards applied science and serving the needs of industry. Comprehensive universities however scored markedly high with regard to the facilitation of NRF funding (8.8 out of 10). Although the differences between the three university groupings appear to be relatively substantial, especially as far as the facilitation of NRF funding and relevance is concerned, the differences are not statistically significant (based on the results of non-parametric Kruskal-Wallis tests).

The facilitation of relevance is highest amongst departments that offer both undergraduate and postgraduate courses (mean score of 8.8 out of 10). This is not surprising because the alignment of undergraduate courses with postgraduate requirements is a key element in the particular measure of relevance. A comparison of the mean component scores by the level of training programme resulted in statistically significant differences being detected for two components: facilitation of relevance and the facilitation of industry networks.

A series of Mann-Whitney tests revealed statistically significant differences for three of the four components between programmes classified as ‘core biotechnology’ and ‘biotechnology related’. The exception is the component that measures the facilitation of industry funding. In all cases of statistical significance the highest mean scores are associated with departments that have a stronger and more direct link with biotechnology training.

Lastly, a breakdown of the component scores by biotechnological domain reveals that, in any domain, the facilitation of NRF funding is the most prominent, together with the strive for relevant training.
Other institutional activities that facilitate the entrance of students into the biotechnology sector

The respondents were granted the opportunity to specify any additional actions that are taken by their departments to facilitate the entrance of students into the biotechnology sector. A variety of ways exist in which the respective universities and departments promote the uptake of biotechnology amongst high school students.

[Our university school] regularly sends representatives to secondary schools in Johannesburg to inform Grade 11 and 12 students of potential careers that can be pursued by choosing to do a BSc through [our university school]; these include biotechnology related options. Presentations of biotech-related careers are also presented during [our university’s] open-day.

We promote biotechnology by exhibits during expo events for senior school groups.

Effort is also made at undergraduate level to encourage students to pursue postgraduate studies in biotechnology. These efforts range from the provision of biotechnology related courses and work assignments during undergraduate level to formal presentations conducted by relevant departments.

Our students are encouraged to register for modules with biotechnology content. In their second year four modules are recommended. These modules are offered by the Department of Biotechnology. In this way we infuse a high level of biotechnology content into their degree programme.

The undergraduate BSc Biotechnology degree at [our university] is designed in such a way that it enables students to continue with a BSc (Hons) and subsequent MSc or PhD post graduate study programmes in Biotechnology in either the Genetics, Biochemistry, Plant Sciences or Microbiology and Plant Pathology Departments. The only provision is a selection of appropriate third year study modules in their field of interest.

... lunch time seminars by invited guests from within the university and from industry provide further exposure for current undergraduate and postgraduate students to biotechnology related research and potential careers ... academics from various disciplines in the school (including biotechnology related disciplines) are given the opportunity to address final year undergraduate students on possible choices for Honours and subsequent study.

Once at the postgraduate level of study, efforts are sought to broaden student exposure to this field and relevant equipment.

Our introductory course introduces postgraduate students at Honours level to the services and facilities we provide – from light microscopy and electron microscopy to X-ray microanalysis and image analysis. This is followed up by one-on-one training
when their projects require it.

... and, where appropriate, we try to expose our students to research conditions overseas by sending them to other laboratories to learn new techniques.

First-rate supervisory capabilities and state of the art equipment are also included as strong incentives drawing students into further biotechnology study.

We try to attract postgraduates through having a large number of NRF-rated academics and modern equipment for biotechnology.

Departments that participate in the biotechnology programme are all required to have the necessary infrastructure, research programmes, supervisory capacity and research track record to support postgraduate biotechnology students and research projects.

Obtaining state of the art equipment that is used in drug discovery, proteomics and vaccine development. Ensuring a quality of supervision in fundamental and applied research that will equip students for a career in biotechnology.

Various respondents also boast of close links maintained with relevant industry and research institutions. This is used to garner greater exposure for students and, in certain instances, may serve as a source for future funding or employment.

We are currently arranging for our undergraduate students to spend practical time within various industry facilities. These sessions are designed to expose the student to practical biotechnology challenges, as well as the means and instruments available to meet those challenges.

We have two dedicated institutes at the university within the Faculty of Natural and Agricultural Sciences that directly link to the biotechnology industries and that act as interface between the students and the industry.

All our research programmes are by default industry sponsored. As a consequence all students are exposed [to industry] at all stages of their research.

Lastly, many respondents also encourage their students to attend and offer contributions to various conferences, expos and forums.

**Insights and suggestions as to how universities can promote biotechnology amongst students**

A major concern expressed by many of the respondents relates to the provision of financial assistance. These respondents felt that there were insufficient funds allocated to bursaries for students and research equipment and materials.

To my mind, the biggest constraint on students pursuing further research in biotechnology is funding. Our students are battling to be able to afford to study further
as they are unable to source bursaries. In our laboratory, of 15 MSc students, only 2 were able to source their own bursaries this year. It is also very difficult for younger lecturers to be able to find research funding to support their postgraduate students and to purchase new equipment which may be needed.

There are several excellent students who receive their B-degrees with distinction, who never received any form of bursary during their undergraduate studies. Undergraduate mentorship programmes do address some of the issues in retaining these students; however it still does not redress the bursaries problem.

A very significant finding from this survey was the prominent perception that the local biotechnology industry is not able to provide employment opportunities for students graduating with biotechnology degrees. This seemingly contradicts the commonly held belief that industry is undersupplied with skilled biotechnology graduates. There may be an issue with the ‘type’ or specific field of biotechnology skills required.

There is a huge interest in biotechnology – I am not sure that the career opportunities exist to further promote it amongst students.

The South African biotechnology industry has to expand and have careers that reward employees well. Currently career opportunities are not attractive.

This finding is seemingly confirmed by the reported perception of risk that students have with regard to future employment in biotechnology related fields.

A constraining factor, particularly with plant biotechnology, is being able to convince students that they will be able to obtain jobs and earn an adequate living by pursuing a degree in biotechnology. Most students perceive careers in biotechnology to be risky in terms of being able to secure a job after completing their degrees and therefore opt for alternate fields of scientific study. It might help if industrial players make themselves more “visible” to students at universities, either through pamphlets or by giving more seminars so that students get a better sense of their options. While this is done to some extent already, I think it could be expanded.

Another concern and constraint relates to the technical expertise and the potential role of the universities of technology (former technikons). This may also involve the training of personnel to undertake high-level repairs.

While I believe that universities can play a key role in promoting biotechnology I am against technical facilities in universities employing only university graduates. We should be promoting the former technikons to be training technically competent people to be performing the vital linking role between technology and academic research. There is a worldwide shortage of persons trained to perform high-level repairs and maintenance to high-tech equipment. I believe that this is causing cost escalations and stunting the development of effective, efficient biotechnology services.
The extent of exposure of high school and undergraduate students to biotechnology also came under the spotlight.

Career choices are usually made prior to admittance at universities of technology. There is some, but very little movement from one field to another. Hence, the effort should be at secondary school level.

Most students know little about biotechnology when they start with university. In order to promote biotechnology, we need to invest time and effort in the grade 11 and 12 learners. Get schools involved in biotechnological projects.

Also emphasised was the importance of university links with industry and related research institutes.

I think that institutions could come up with a more formal way of getting students some industrial experience. When I was an undergraduate in the UK I did a sandwich course, which means that the course took 4 years, but I spent about a year working in industry which was paid for by that industry. That gave me a good idea that I wanted to carry on in research and gave me a good industrial background.

At a postgraduate level there is a need for increased interaction with the biotechnology sector via collaborative research initiatives and greater exposure to representatives from biotechnology-related industries.

Staff also needs to be adequately trained and provided with the necessary equipment and infrastructure.

Having competent and enthusiastic supervisors, together with adequate lab facilities, are probably the most effective in steering postgraduates towards a career in science, specifically in biotechnology.

Exposure to biotechnology and related fields at research institutions during senior years of study. Lecturers must be well informed on biotechnology and the application thereof in agriculture (maybe a one day/half day teaching course?).

Finally, a number of respondents disagreed with the designation of biotechnology as a field of study or field for future employment. The view is expounded that this is a flawed assumption and that biotechnology refers to a methodology and should more accurately be portrayed as a tool. These respondents seem skeptical of the wisdom of presenting biotechnology as a holistic field.

Biotechnology is not a discipline but multidisciplinary and includes amongst others, biochemistry, genetics, microbiology, mathematical modeling, chemical engineering and molecular biology. There are also a vast number of definitions for biotechnology, the most embracing of which is “economic biology”. ... Because of the multidisciplinary nature of biotechnology, my view is that attempting to train
students in biotechnology is an error and will make a “jack of all trades and a master of none”. If one requires a team to tackle a biotechnology project you do not want half a dozen “biotechnologists” who have been partly trained in many fields .... So train the sub disciplines properly and one will be able to assemble a team to take on any biotechnology project by adjusting the members of the team.

I think it is very dangerous to promote biotechnology as a career, as it is merely a tool to achieving a career in plant pathology or plant breeding, for example. As such we seek to teach the strengths and weaknesses of current biotechnology as a toolbox with a number of tools which can be used to solve technical questions in plant pathology or plant breeding .... We do not see biotechnology as a field on its own .... We see biotechnology as a tool to be used by real disciplines, and therefore we teach it as such a tool to be used by plant pathologists and plant breeders.

**DISCUSSION**

The identification of biotechnology related training programmes is not without caveats. For instance, it cannot be assumed that if one chemical engineering department specifies a link with biotechnology it also applies for the same departments at other universities. Even in the case of genetics, which is traditionally seen as significantly connected to biotechnology, not all genetics departments in the survey reported a link with biotechnology. Similar arguments apply to food biotechnology. One head of a food technology department in the survey remarked: *We train food technologists and not biotechnologists, so the questionnaire is not really relevant.*

This remark cannot be separated from the difference in perspective of biotechnology as a portfolio of analytical tools versus biotechnology as an academic discipline. The institutionalisation of biotechnology as an academic discipline (which, at some universities, is expressed in the establishment of biotechnology as a separate department alongside other science departments such as food technology, genetics, etc.), suggests that biotechnology becomes a separate academic entity, with the risk that it is no longer seen as a domain of expertise that cuts across various science disciplines.

Although not a specific focus, models of institutional arrangements with regard to the placement of biotechnological training in the academic setting nevertheless also emerged (during the process of identifying relevant departments as well as in the survey responses). One such model is the formation of schools, where biotechnology programmes are jointly run by different departments or sub-units within a school. Another model is through specialist research centres dedicated to biotechnology. The research members at these centres often teach in the interdisciplinary programmes that are offered by the centre or by the department/faculty/school where the centre is hosted, or in programmes that are jointly run by different departments. In both cases (schools and centres as opposed to academic departments) biotechnology maintains its perspective as being ‘cross-cutting’ and not a separate academic entity.
That being said, even in instances where biotechnology becomes a new separate academic department, it can still maintain its cross-cutting nature, for instance, by offering modules to other departments. A study on the organisation of biotechnology at academic institutions, and the extent to which the particular mode of organisation promotes biotechnology needs to be explored in future studies.

The global political support for the promotion of biotechnology, and the special treatment thereof within political agendas, is partly responsible for the growth of biotechnology as a separate discipline rather than a tool to be used by traditional disciplines. The tension between biotechnology as a discipline and biotechnology as a portfolio of interdisciplinary tools cannot go unnoticed. This not only underlies the ambiguity of the term amongst academics but also underlines the conundrum currently faced by course planners. Is it feasible to support the coordination and eventual integration of these traditional disciplines within new structures that are constituted around the notion of biotechnology or is it advisable to focus attention on the strengthening of traditional disciplines that underlie biotechnology (namely biochemistry, microbiology and molecular biology, genetics, chemical engineering and a branch of mathematics known as mathematical modeling)? If the first is indeed feasible, considerations of what should be incorporated into such a conception of a biotechnology field are paramount.

The relation between departments/schools (that offer biotechnology related programmes) and the biotech industry also requires particular attention. The survey results reveal relatively weak linkages between the academic and industry sectors in biotechnology. The most frequently mentioned form of interaction between the two sectors, that could facilitate the uptake of students in the biotech industry, is the participation of postgraduate students at conferences where the biotech industry is represented (42% of respondents said that their department always assist in this regard). Moreover, although the facilitation of NRF funding is relatively prominent, the survey also suggests that this action is not always accompanied by the facilitation of industry funding for students. On the other hand, the lack of facilitation of industry funding does not imply that the respondents (or their departments) do not receive any industry funding at all. In fact, industry funding (for biotechnological related work) often does not come from biotechnology industries but from other industries. For instance, in wine biotechnology it is mainly the wine industry (as opposed to specific biotech industries) that funds the research of researchers and students. Two points need to be made here: firstly, many departments do not see it as their primary function to act as mediators in securing industry funding for students and, secondly, one must caution against defining the notion of ‘biotechnology industry’ too narrowly.

The biotechnology industry, or specifically, organisations involved in commercial biotechnology in South Africa, appears to be small, based on the views of the survey respondents. The lack of funding opportunities, from sources other than the NRF and its associated initiatives, is thus a real concern and an issue for further investigation. Also, as said, it is important to focus on mechanisms to close the ‘linkage gap’ between the biotechnology and related training programmes at universities, on the
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one hand, and the biotechnology and related industries, on the other hand. However, various factors need to be kept in mind: the ‘dosage’ and ‘concentration’ of the biotechnological training provided (i.e. whether students are from core biotechnology programmes or from peripheral programmes less strongly related to biotechnology); the notion of what constitutes the biotechnology industry (core biotechnology companies, biotechnology active companies or companies involved in ad hoc biotechnology work); the geographic location of the biotechnology companies (local or foreign); and the alignment of undergraduate and postgraduate programmes in biotechnology to provide an ‘industry ready student’ – the latter not only applies for programmes within the same university but also for programmes across universities.

NOTE
1 These are Cape Biotech (Western Cape), Lifelab (KwaZulu-Natal), BioPad (Gauteng) and a national innovation centre for plant biotech, PlantBio (also in KwaZulu-Natal).

REFERENCES