2011

GOOD PRACTICE REPORT:
Assessment of science, technology, engineering and mathematics (STEM) students

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Contents

Since the report was commissioned, more projects and fellowships which deal with assessment of science, technology, engineering and mathematics (STEM) students were completed. These were added into the report by ALTC. For completeness, projects and fellowships in progress which cover aspects of assessment of STEM students are also included in the report by ALTC. These projects and fellowships are marked with an asterisk at the end of the titles.

Overview

Assessment in undergraduate science, technology, engineering and mathematics (STEM) is predominantly in the form of high stakes end-of-topic examinations. This is summative assessment. Other types of assessment occur during the course of a topic, such as take home assignments, tutorial exercises or laboratory reports. These are usually intended to be more formative, although for various reasons the feedback from them can be quite limited.

This customary regime of assessment supports the accepted view of an undergraduate education in STEM, that its primary goal is to produce graduates with an expertise in one of the STEM disciplines. In science these discipline specialisations might be physics, chemistry or biology, in engineering they might be civil, chemical, or electronic and in mathematics, pure, applied or statistics. There are other specialties, and even specialisations within those cited; sub-disciplines like organic chemistry or theoretical physics.

Despite the great diversity of disciplines there is considerable commonality in the knowledge base of subjects on which they all draw, particularly mathematics, physics, chemistry and biology. Consequently another educational goal of various STEM disciplines is to provide such training in their discipline as is necessary for its application in others. 'Mathematics for Engineers', 'Physics for Life Sciences' and 'Discrete Mathematics for Computer Science' are examples of such 'service teaching'. In fact, a large part of teaching in science and mathematics is of this service character.

Service teaching has been treated, and mostly still is, as a 'dumbed down' version of 'real' discipline teaching. Assessment is modified accordingly but the underlying assessment regime and rationale remain the same. After all, from this point of view 'service' students are merely being trained to be somewhat less expert than those who would become true experts in their discipline. In short, the prevailing ideology is that, no matter what the student focus or interest, a STEM education amounts to an induction into a STEM discipline, the differences being more of degree than kind; it's all about the discipline.

Induction into a STEM discipline, whatever the mix of foundational and specialty subjects, amounts to learning tightly interwoven concepts and techniques. For example, students in physics will learn how to analyse motion through Newton's laws involving concepts of velocity, acceleration, force, mass and principles of superposition, along with the techniques of differential and integral calculus and vector algebra that realise such an analysis. Students in engineering might learn such physics in order to apply it to design principles for automotive safety.

The concepts and techniques in STEM disciplines are taught through paradigmatic examples of their use, which are in general highly simplified rather than practical and 'real life', in order to elucidate basic ideas. These concepts, techniques and paradigms are known in the educational literature as 'content'. Science and mathematics subjects at secondary level and all STEM subjects at university are regarded as content-heavy because of the overwhelming emphasis on learning concepts and techniques by exercising them through paradigm examples; and this is even before considering the unfortunate tendency to include too many of them.

In short, the traditional view is that STEM education is about induction into disciplines by absorbing their content. Such an attitude brings with it an unwillingness to address the diversity of students who come to study various STEM disciplines. With the expansion of the higher education system and funding based on student demand this attitude is being significantly challenged, and with it the traditional views of assessment.

The traditional view of STEM assessment is that it is to test whether and to what extent discipline content has indeed been absorbed, with weekly or fortnightly assignments to help students soak it up, and to ensure that they do so at a reasonable rate. The extent to which the traditional assessment regime achieves these goals is open to question but is largely taken for granted by the majority of practitioners. Some of its limitations may be noted and lamented but, until recently, not with any significant view to change, outside the work of isolated individuals.

The expansion of higher education systems makes these traditional views increasingly untenable. Most students come to university with interests and life aspirations that don't connect directly with an induction into a STEM discipline via abstract concepts and techniques, acquired through highly stylised examples and problems that appear to have no bearing on those interests and aspirations. The way in which they will need to exercise their STEM knowledge does not usually focus on technical skill in the conceptual and technical foundations, which is the preoccupation of many STEM courses. Moreover, students often arrive lacking the background ideas and capabilities that University STEM courses assume as their starting point, creating a significant barrier to such an induction into a discipline.

There are a number of individuals, and some faculties, that are challenging these traditional views, and attempting to develop STEM courses that cater to a greater diversity of student interests and backgrounds. A reconsideration of the role of assessment and development of new models of assessment are essential to the sustainability of these initiatives.

There is a considerable literature, national and international, on assessment in relation to primary and secondary education, and there are learned journals which publish papers on assessment in higher education. However, while this literature could inform a reconsideration of STEM assessment, most academics teaching STEM subjects do not question the accepted regime at such a fundamental level that they would be motivated to access it, and if they did they would not find it immediately relevant. Ironically, academics teaching STEM subjects find the learned literature on assessment as remote and seemingly unconnected to their interests and concerns as their students find traditional STEM subjects are to theirs.

The issue therefore, for an agency such as the ALTC that wants to promote change in the culture of STEM teaching and learning, is not necessarily to generate new ideas about assessment, since there are plenty of those lying around unused, but rather to connect academics who teach STEM subjects with ideas about assessment in a form that sheds light on the challenges with which they are struggling and offers pathways to solutions.

The ALTC and its predecessor AUTC have supported the production of resources of this kind, and they represent good first steps. Among the best examples are two related pieces of work from the Centre for the Study of Higher Education (CSHE). The website Assessing Learning in Australian Universities discusses some common 'down to earth' issues that most academics would recognize as challenging traditional approaches to assessment. These are online assessment, dealing with large classes, plagiarism, assessing group work and advice for students unfamiliar with assessment practices in higher education. It discusses the imperatives driving change in assessment, provides advice on faculty processes for renewing assessment policies and provides a framework of core principles for good assessment practice.

This work is referenced by a number of university professional development units. However, university teachers generally regard their discipline as the source of authority for their teaching, and regrettably their ideas and reflections about it are not influenced much beyond the staff common room or departmental committees. Their ideas about pedagogy, and particularly about assessment and how to interpret it, don't tap into anything resembling the national and international research culture that informs the content of their teaching.

The website BioAssess attempts to address this by appealing directly to the bioscience community. It recognizes that the particular preoccupations and ways of thinking that characterize a discipline, and the organisational culture within which it operates, make the discipline-specific translation of general ideas on teaching, learning, and particularly assessment, a highly non-trivial exercise. It also recognizes that to engage the bioscience community in these ideas its practitioners need to see the potential of them in the context of their own teaching.

The website draws on *Assessing Learning in Australian Universities*, setting a context of key issues in curriculum design and assessment with sections discussing general principles of assessment, types of assessment, and an interesting summary of learning objectives informed by discussion with the bioscience community. It creates engagement by involving bioscience educators in identification and selection of examples of best practice from their own practice, that are compiled as a database and used to illustrate key issues in assessment and curriculum design.

The BioAssess team undertook several roadshows around Australia to introduce the website, promote its ideas about assessment and to invite comparisons with and further contributions to its database of best practice. The website's ideas about pedagogy and assessment thereby achieved something of the same level of critical discussion, challenge and appraisal as does research, rather than remaining confined within departmental common rooms. It is a strategy well worth promoting in other STEM disciplines, particularly as a means of engaging them with resources like *Assessing Learning in Australian Universities*

The BRACElet project provides a case study in building a national community of practice that challenges presumptions and interpretations of traditional STEM assessment. It promoted a scientific approach, an hypothesis testing evidence based approach, to making inferences from end-of-year examination results about why IT students are or are not capable of writing computer programs.

By forming a national (indeed, trans-Tasman) community of practice willing to compare examination questions and results across institutions, the project showed how it is possible to devise questions that test cherished explanations. For example, the project observed questions for which similar proportions of students in each of several universities found difficult, irrespective of whether the students at one university performed better or worse than another overall. This confounded the standard tearoom explanation that differences in performance are a consequence of differences in quality of students. Staff were driven instead to consider notions of cognitive skill more analytically, and how their examination questions relate to such skills.

Critical to the success of this project was the growth of the community of practice, and capacity building within it, through several years of meetings allied to ICT conferences, and the use of ICT for managing communications and data. The project's approach would be particularly valuable to many other disciplines, particularly those involving quantitative skills, where university teachers have long lamented low progression and retention rates; the folklore blaming this on lack of preparation and/or native ability of students. The BRACElet approach, and the kind of analysis it provokes, fits well with current ideas about threshold concepts and their role in learning.

The use of ICT is a major preoccupation in teaching and learning and in assessment. In STEM it has a dark side. The learning of concepts and techniques through examples and exercises requires a lot of feedback to help students over misconceptions, encourage practice and reinforce good judgment. Provision of such feedback is time consuming and relatively expensive, and as class sizes have grown the level of such feedback has had to be reduced. The short answer question has become the main tool for providing it. Once the quality of such feedback becomes so rudimentary that even a computer can provide it, ICT becomes a natural labour saving device and its use has become widespread in this regard, particularly in STEM subjects.

The dark side of this use of ICT in formative assessment is that it entrenches a low quality approach in pursuit of efficiency gains. There are many projects that have aimed to translate the standard content focused approach to assessment feedback unchanged into an online environment. An outstanding example counter to this approach is the ALTC project **Online assessment feedback as an instrument of reflective learning practice in Human Biology**.

Its report is significant for its emphasis on student characteristics, experience and expectations of feedback as much as on the discipline content of the feedback. It correlates student responses to multiple choice questions with their age, experience, gender, hours of paid employment, and other characteristics. It provides convincing evidence that speculation about student performance in assessment cannot be made sensibly without reference to such background, and that automated multiple choice questions provide real opportunity to gather and analyse such data.

Not only does the report move beyond content to address the impact of student diversity on assessment, but goes beyond the confines of its home university in looking for better ideas. It uncovers one of the best and most accessible resources on formative assessment, the UK Higher Education Academy's FAST project (Formative Assessment in Science Teaching http://www.open.ac.uk/fast/. This project includes work by Glover surveying and reviewing student attitudes to feedback, showing for example that students often only take note of marks, or of feedback on wrong answers only, or ignore verbal feedback. The point is that students' ability to recognize and exploit feedback is a learned thing itself. The project offers a simple reflective instrument designed to promote such learning.

The ALTC project **Linuxgym: a sustainable and easy-to-use automated developmental assessment tool for computer scripting skills** adverts to another example of the creative use of ICT in developing formative feedback, one that unfortunately appears lost. The essence of this project is to use the computer's own internal workings to provide automated formative feedback on whether it is being programmed correctly. When a program is submitted, a compiler program parses it and translates it into machine language for execution. The idea is to tap into this parsing process so that the computer can alert students to bugs in their programs, with some diagnosis of where things might have gone wrong.

Many STEM teachers lament the fact that a great deal of the fundamental technique that they teach, and indeed a lot of not so fundamental ones, have been developed into software systems, so that practitioners no longer need to be proficient in them. It is an extension of the complaint that calculators and spreadsheets, now accessible from any iPhone, relieve people of the need for proficiency in arithmetic. However, if computers can be programmed to carry out these techniques, then they can also deliver diagnoses as to where a human may have got them wrong and why. Many STEM disciplines therefore have the same opportunity as in the Linuxgym project, to use their automated systems to deliver high quality formative feedback.

These are examples of leading ideas developed in Australia for the adaptation of STEM assessment to a more inclusive paradigm of STEM teaching and learning, and to deliver richer formative feedback so essential to the development of technical skill, and whose increasing paucity is quite likely a major factor in student alienation from STEM disciplines. They represent an early stage in this campaign, and show clearly the kind of projects that, building on them, will provide substantial discipline based resources to support the growth of the more inclusive paradigm.

Completed ALTC projects and fellowships

(The year at the end of each title is the year in which the project or fellowship is funded. Project/fellowship titles are live links to the resources.)

Science

Diagnostic assessment for biological sciences (PP7-350)*

Discipline: Natural and physical sciences
Project priority area: Academic standards, assessment practices and reporting
Final report: Diagnostic assessment for biological sciences – development of a concept inventory (Tony Wright, Susan Hamilton) (The University of Queensland) (2011)

Aim: The project aimed to develop a validated web-based assessment tool (the concept inventory) to assess students' understanding of key concepts and the difficulties they face, thus providing educators with feedback about students' learning, their teaching practice, and curricula. It also aimed to develop a model for the future development of a complete and comprehensive statement of key concepts and associated concept inventories for the biological science.

Problem addressed:
The setting for the project arose from the confluence of two major trends in the fields of science and education. Firstly the continuous development in the molecular aspects in the science discipline made it challenging for students to grasp the body of knowledge and daunting for academics to provide a rich, authentic learning experience. Secondly, concept inventories were becoming established in the field of educational assessment for diagnostic and formative assessment. However, there was a conspicuous gap in the fields of biochemistry and molecular biology.

OUTCOMES AND TOOLS:

The project outcomes include:

- **An inventory** (a 40-minute test comprising 100 true/false test items) designed for use with students entering their first biochemistry course (typically in year two of undergraduate study). It iss designed to diagnose understanding of fundamental concepts in chemistry and biology upon which biochemistry builds, and has been validated through trial tests with more than 1000 students nationally and internationally.

- A package comprising **a set of "teaching objects"** that are designed to assist educators to focus their teaching around the list of big conceptual ideas in biochemistry. The resources support a range of activities – interactive lecture, workshop, computer-based tutorial and wet laboratory, formative and summative assessment tasks – with an emphasis on student-centred learning. Educators, depending on their needs, can use the package flexibly.

Project website: http://www.lifescinventory.edu.au/

* This project was completed after this report was commissioned. ALTC has included the summary in the report for completeness.

Double degrees: research pathways, enabling cross-disciplinarity and enhancing international competitiveness (CG9-1000)

This project makes detailed studies of several aspects of 'dual' degrees based on data from the five ATN universities, these being the project participants. A considerable part of this data is offered as a 170 page appendix containing results, academic transcripts and examples of dual degree students' work. The report itself is a more concise and informative 18 pages, explaining clearly and convincingly its rationale and approach.

Typical examples of dual degrees are a BE-BMedSci, BE-BSc or BE-BBus and the study confines itself to those having engineering as a constituent. The first issue considered is the terms 'double', 'joint' or 'combined' degree, often taken to imply that students cover the material of each degree to the same extent as if it were taken independently. However the study confirms that the degrees are combined by deleting significant subjects from each. The first recommendation of the report is to acknowledge this by avoiding the use of such terms and standardizing on the terminology of dual degree.

Subjects are omitted from constituent degrees so that the dual can be completed in five to five and a half years rather than the seven years that typically would be required to take them serially. The argument for omitting subjects is that some aspect of one of the degrees serves as recognition for prior learning (RPL) for subjects in the other. The study applies typical standards of RPL to the dual degrees and finds that that they generally fail to meet them.

The value of dual degrees is taken to lie in their cross-disciplinary character that makes them greater than the sum of their constituent degrees. A major finding of the report is to confirm long standing suspicions that most dual degrees comprise two degrees operating side by side and for the most part non-interacting. It recommends joint supervision of final year projects and joint curriculum committees as first steps to improving this.

More than this, the study finds that dual degrees entail significant deficits both for learning and for the student experience. Mathematics is significantly reduced, for example, and the deletion of submajors stands to curtail depth and coherence of learning. In student experience, dual degree students find it harder to maintain connection with a given cohort of students and relationships with class mates.

The report highlights that academics value dual degrees for their power to attract high achieving students, but lament that their sacrifice of specialization inhibits pathways to research and higher degrees. By contrast employers generally do not value higher degrees, and value generic skills over the breadth of content gained via dual degrees.

While the report clarifies many issues posed by dual degrees and makes some simple and sensible recommendations to deal with them, there are clearly deeper conflicts remaining that require a lot more thought and hard decision making. The champions of the report, being senior academics, have good opportunity to promulgate its findings among the engineering deans and Engineers Australia in pursuit of institutional change.

Educational technologies: Enhancing the learning of scientific inquiry skills for bioscience students in Australian universities (CG8-763) (2008)

This project is less about educational technologies and more a study of current teaching of scientific inquiry skills. It draws on the approaches of 26 different bioscience topics in nine different universities and in 11 different bioscience areas. It describes these in terms of a framework based on four elements, the degree of inquiry inherent in student tasks, the degree of student independence in performing those tasks, the inquiry learning objectives expected and the learning environment in which the tasks were carried out (lectures, practicals, online, outside class, etc).

The framework brings a useful and coherent perspective on the diversity of practice exhibited by these case studies. It is perhaps more important that it encourages the reader to a deeper analysis of their own ideas and efforts in inquiry learning. The case studies provide exemplars of how to think about ideas and experiences in terms of a conceptual framework, as well as providing new ideas about how inquiry learning might be fostered.

The project also identifies and details six of the 26 cases as instances of innovative practice, and these might be a good place for the interested reader to start. These cases provide examples of inquiry based teaching from those that have very modest goals to those that that want to give students an authentic experience as a scientific researcher, and from those that require almost no extra resources to those that require considerable restructure and support.

It is at this stage that the project considers the uses to which educational technology is put. Its use is categorized as being tools of scientific trade (data base searching for example), as learning management mechanisms and as communication systems. It is notable that it is often such uses of IT systems, particularly the last two, which make some of the innovations possible. It is also notable that the project finds little use of IT directed at conceptual learning, and some resistance to any use of it at all.

The project provides a good example of the dichotomy between how scientists teach and how they do research. For while their research is based on a scientific approach to their inquiries, and the report investigates their views on this in some detail, their evaluation of their teaching remains very faith based and accepts conclusions that they would never accept in a research setting. The project supplies some simple ideas drawn from the literature to show how an evidence base can be introduced into the evaluation of inquiry teaching initiatives.

The project has produced *Teaching scientific inquiry skills: A handbook for bioscience educators in Australian universities* http://www.scientificinquiry.meu.unimelb.edu.au, which sets out all of its ideas and findings accessibly and informatively. It should be highly influential among bioscience educators, and a model for other disciplines who want to encourage science inquiry teaching and learning among their staff and students.

Enhancing the assessment of learning in Australian higher education: Biological sciences (PP5-32) (2005)

This project aims to generate critical awareness of and change in assessment practices in the biosciences. Its website offers a discipline-focussed and comprehensive synthesis of good practice in bioscience assessment. It is based on elaborating the ideas of the foundational work *Assessing Learning in Australian Universities* in the context of the biosciences and engaging the bioscience community with them.

It recognizes that the particular preoccupations and ways of thinking that characterize a discipline make the discipline specific translation of general ideas on teaching, learning, and particularly assessment, a highly non-trivial exercise. It also recognises that to engage the bioscience community in these ideas its practitioners need to see their potential in the context of their own teaching. It achieves this by dialogue to engage their views, and by involving them in identification and selection of examples of best practice. The project emphasises that assessment needs to be considered in the context of learning outcomes and curriculum design.

The project outcomes are the website <www.bioassess.edu.au> and the community of practice formed through its genesis and that provided input into it. The project report gives a good account of the thinking that underlies the project, its philosophy and approach, the extensive consultation through interviews of staff and focus groups of students, the dissemination process through UniServe, ALTC and other national conferences, and the engagement of bioscience educators through the provision of examples for a good practice database.

The website contains the database of good practice examples so collected. While they can be accessed directly and individually, the website is constructed to access them in the context of key issues in curriculum design and assessment. It has preparatory sections discussing general principles of assessment, types of assessment, and an interesting summary of learning objectives informed by discussion with the bioscience community.

The key issues considered in assessment are plagiarism, generic skills, large classes, student diversity, involving sessional staff, feedback and standards. Curriculum issues considered are benchmarking, resource constraints, planning and review, curriculum crowding, outcomes and assessment and the teaching-research nexus. Each of these has pages providing a brief critical overview articulating with a list of relevant good practice examples.

The project represents a valuable resource and a substantial capacity building exercise for enhancing assessment and curriculum design, which could well be emulated by other disciplines.

Extending teaching and learning initiatives in the cross-disciplinary field of Biotechnology (DS6-601) (2006)

The report is about biotechnology programs in general and was not focused on teaching and learning issues specifically. It aims for a holistic look at where the field of biotechnology is heading and touches on the implications of its evolution for curriculum design and innovation. Pages 15–39 summarise its findings on 11 project tasks intended to implement its aims, supported by seven appendices covering 124 pages.

Key challenges for biotechnology curriculum are identified as: the necessity, as with engineering, for industry experience (task three) and greater emphasis on generic graduate attributes (task eight); its multi-disciplinary nature (task one); the need for rapid change congruent with the growth of science and the evolution of industry in the area; and the problems of managing niche disciplines in the current university climate. This last is dealt with by distilling the experience of the team into a booklet for establishing a biotechnology discipline (task nine).

The report acknowledges the critical role of professional bodies, especially in addressing tasks three and eight. The project set out to establish a strong connection between the emerging discipline of biotechnology and the emerging professional body AusBiotech (task seven). A major outcome of the project is the formation of an education committee of AusBiotech at its executive level, with the project team included among its inaugural members. Its genesis and final form are described in detail in task seven.

The report on task one appears to make no progress beyond its predecessor study, in articulating the implications of the interdisciplinary nature of biotechnology. A paper (Appendix one) presents a wide ranging discussion of the nature of inter/trans/multi disciplinarity from which it draws some educational models.

Appendix seven provides background and reports on a survey of biotechnology industry placement schemes in Australian universities. Its findings are reported under task three. The variety of arrangements and methods of addressing them will be particularly informative to those in the discipline, and it would be worth comparing these findings with those of other work placement studies for their differences and similarities. One of the main problems lies in the formative state of biotechnology industry, whose companies are generally not sufficiently large or diverse to accommodate the needs of students in placements. The personal reflections of the team do mention strategies to address this.

Task five describes the influence of the project on the team members teaching strategies, and concludes with a brief useful overview of problem based learning. Task eight summarises the findings of a mapping exercise of graduate attributes described in Appendix four. It derived a list from institutional lists and mapped them to the biotechnology programs of participating institutions. It noted the difficulty of meaningfully identifying attributes and found that they were emphasised disproportionately in interdisciplinary and professional topics.

Online assessment feedback as an instrument of reflective learning practice in Human Biology (PP5-41) (2005)

This report is brief, its key sections go from pages 13 to 37, but there is a great deal to be learned by all with an interest in improving online assessment.

The aim of the project is to enhance online multiple choice questionnaires (MCQs) administered through standard student systems, WebCT and Blackboard, by the addition of two mutually supporting elements, automated explanatory feedback, and a questionnaire prompting reflection on that feedback. While the project focus is on human biology, its approach is adaptable to any discipline.

The report is significant for its emphasis on student characteristics, experience and expectations of feedback as much as on the discipline content of the feedback. It provides the practitioner with a concise and compelling perspective on the interplay between these aspects and how they were brought to bear on the design of the feedback and the reflection instrument.

By surveying their student population for age, experience, gender, hours of paid employment, and other characteristics, the project was able to correlate these with student responses to MCQs. Practitioners reading this part of the report will surely be convinced, if they were not already, that speculation about student performance in assessment cannot be made sensibly without reference to such background, and that automated MCQs provide real opportunity to gather and analyse such data.

The report draws on FAST (Formative Assessment in Science Teaching), a three-year project funded by the UK Higher Education Academy http://www.open.ac.uk/fast/. In particular it appeals to the work of Glover 2002–3 (op. cit. Resources/Project Reports) which surveys and reviews student attitudes to feedback, showing for example that students often only take note of marks, or of feedback on wrong answers only, or ignore verbal feedback. The point is that students' ability to recognize and exploit feedback is a learned thing itself. The simple reflective instrument developed in the project is designed to promote such learning.

The project produced a set of guidelines for the writing of feedback responses (Report appendix 1b) based on an analysis of errors and patterns of them in the responses to a large number of MCQs, and on principles such as the 11 conditions of effective formative assessment identified in FAST.

The report notes that for a variety of reasons it had not been possible at the time of writing to make its feedback enhanced system generally available. However, the value of the report lies as much in engaging others in such formative thinking about assessment as it does in the particular product developed. It sets a standard in its approach that could usefully be adopted for other teaching and learning projects.

Tertiary Science Education in the 21st Century (DS6-596) (2006)

(This report is reviewed by Associate Professor Les Kirkup as the author, Professor John Rice, is the project leader of this project.)

This is an extensive and influential report driven by the Executive of the Australian Council of the Deans of Science (ACDS) that focusses on learning in first year laboratories in biology, chemistry and physics.

Academics, when quizzed, often express the opinion that hands-on laboratory work is vital to the development of undergraduates, but are less well able to articulate just what it *is* that is vital and in what ways the laboratory experiences enhances or develops students' capabilities. It is this issue that is at the heart of the study by Rice et al. Key issues addressed in this report include: the extent to which the goals and purposes of the laboratory have been thought out by academics, especially in the light of the diversity of the student background and intended destinations; how well outcomes of laboratory work have been expressed to students, and; the effectiveness of professional development programs intended to prepare demonstrators for their roles supporting student learning in the laboratory.

A large amount of data on attitudes towards, and experiences of, first year laboratories was gathered through interviews with heads of departments, unit or subject coordinators demonstrators, technical staff and students. The authors sought to capture a snapshot of *what* was happening in first year laboratories across biology, chemistry and physics and just *how* it was happening. Three GO8, three IRU and three ATN institutions took part in the study.

Several themes emerged which have been picked up and influenced other studies supported by the ALTC, including *Teaching scientific inquiry skills: A handbook for bioscience educators in Australian universities* by Elliot et al http://www.altc.edu.au/project-educational-technologies-enhancing-melbourne-2008 and *New perspectives on service teaching: tapping into the student experience* by Kirkup http://www.altc.edu.au/resource-new-perspectives-student-teaching-uts-2009

The report makes several recommendations calculated to foster sector commitment and engage institution policy makers with reconceptualising the role of the laboratory at first year level. Many of the recommendations could be applied to experimental- and observation-based activities at all levels of an undergraduate degree in science. As examples, the suite of recommendations include the call for all curriculum documents to make explicit the relationship between the lecture and laboratory component of a subject, and for the sponsoring of a national project that fosters changes in the system of demonstrating in the laboratory.

The report recognises that it is the associate deans teaching and learning in science and those who will be future leaders in science education that must work actively and cooperatively together if the projects proposed as part of the recommendations are to gain traction.

It is regrettable that the study did not find more examples of where the place of the first year laboratory program in the curriculum had been well thought out with (for example) learning objectives clarified and where other good practices had been employed. The picture painted in some sections, though no doubt representative, is quite gloomy.

Engineering

Curriculum specification and support systems for engineering education that address revised qualification standards (PP8-844) (2008)*

Discipline: Engineering and related technologies
Project priority area: **Curriculum renewal**

Final report: Curriculum specification and support systems for engineering education that address revised qualification standards (Elizabeth Godfrey, Robin King) (University of Technology Sydney, Sydney (Lead), Australasian Association for Engineering Education (AAEE), Australian Council of Engineering Deans, Central Queensland University, Engineers Australia, The University of Melbourne, The University of Queensland, University of South Australia) (2011)

ISSUES ADDRESSED:
Purpose/Aim: The project aimed to underpin and strengthen Australia's engineering education system through informed and systematic curriculum renewal and delivery and support.

Problem addressed: In common with other industrialised nations, engineering in Australia has lost ground in attracting and graduating sufficient domestic students to meet national needs across the range of engineering qualifications offered by the higher education sector. Particular challenges are recruiting more women and Indigenous students into engineering, and the need for continued focus on breaking down the masculine stereotypes of engineering and engineering faculties.

OUTCOMES AND TOOLS:
- The reasons why engineering students leave their programs were explored, and **strategies for reducing attrition proposed in 25 recommendations**, based on evidence drawn from successful interventions.
- **Workshops to support engineering academics** were developed, trialled and evaluated, demonstrating that engineering academics benefit from activities that cover basics of teaching and learning, reflect on new ways of approaching teaching, and interact with engineering colleagues from other institutions.
- Academic and professional engineering communities collaborated to revise Engineers Australia's competency standards for the three accredited engineering qualifications. The **revised standards** include evidence indicators to assist engineering curriculum designers to ensure that the required outcome competencies are met for program accreditation and professional practice.
- Nine universities contributed to a **comprehensive review of the wide and growing range of pathways** to graduate engineering qualifications. Examples of best practice support the 14 recommendations.

Dissemination: Progress reports to meetings of ACED, ALTC Discipline Support Strategy events, Engineers Australia and the Australasian Association for Engineering Education. Several papers on attrition were presented and published in international conferences organised by the American Society for Engineering Education, and the UK Higher Education Academy Engineering Subject Centre. Further dissemination to the engineering education community during 2011 and beyond is planned in the proposed workshop program of the Discipline Support Strategy for Engineering and ICT, and activities of ACED.

* This project was completed after this report was commissioned. ALTC has included the summary in the report for completeness.

Development, deployment and educational assessment of advanced immersive learning environments for process engineering (CG6-21) (2006)

This is a well-written and highly informative report providing insight into the learning potential and learning issues surrounding the development and use of virtual reality systems. The project develops 3D walk-through realizations of two chemical process plants, an oil refinery near Brisbane and a methanol plant near Melbourne.

The most direct motivation from the point of view of a university lecturer lies in providing a means for students to experience actual systems, through which they can explore and elaborate the concepts of their course, without onsite industrial experience. Industry experience is very expensive in time and organization, and harder to obtain as numbers of students grow larger. The idea of this project is to use virtual reality to bring the plant to the student.

However the report promotes substantial new benefits. Participating industries have an interest in such virtual reality environments for site induction, operator training and community awareness, creating a new arena and new imperatives for industry collaboration with universities. Schools could also use them to show students what engineers actually do, and the kind of learning they need to do it, promoting an authentic vision of engineering; something not easy for schools to convey.

The project thus demonstrates the significance of virtual reality systems to professional education in building relationships at all levels from school students through to industry. It could apply as well to more basic areas where direct experience is hard or impossible to achieve, such as in molecular biology and chemistry, ecological systems, planetary geology, physiology and other areas of medicine; anywhere that requires insight into scale, complexity, the behaviour of systems and design of interventions into them.

The report identifies and touches upon significant design issues involved in developing such learning systems, such as the balance between verbal and visual information in choosing between narrative, text and images, and appropriate choice between animation, simulation or visualization. On broad learning design issues it aims for flexibility that will permit educators to develop activities and information relevant to students' level and style of understanding [diversity], allow independent exploration of the system [constructivism] and allow a range of learning depths and extent of concepts.

It would have been good to have these issues illustrated with detailed case studies drawn from the project experience, but perhaps these are in the publications to which the report refers, and are available on the ALTC Exchange. One clear message is that such systems need a team effort for their successful development, involving discipline specialists, professional experts, instructional designers and cognitive psychologists.

The project has won international recognition for its work, and reports increasing adoption among universities in Australia and overseas.

Engineering meta-attributes project (CG6-23) (2006)

Immediate insight into this project can be obtained from its most accessible outputs, which are two single page posters: *The engineering graduate capabilities continuum* (EGCC) and *Engineering curriculum review: process overview* (ECR). Both can be retrieved in PDF from the ALTC Exchange using the search term 'Carew', the name of the project leader. The poster format was decided upon in the belief that diagrammatic representations, familiar in flow charts and process diagrams, would communicate their ideas more effectively to engineers, and this may well be true of other audiences.

The EGCC lists institutional (UoW) graduate qualities down the left hand side and graduate attributes from an Engineers Australia accredited program down the right. Four intervening columns parallel these listing ten graduate capabilities relevant to these qualities/attributes and elaborating them into indicators of three successive levels of attainment. The EGCC is intended for use in assessing student portfolios, in engineering course design and for auditing and reporting on assessment tasks.

The EGCC was inspired by the observation that a great deal of teaching innovation occurs at the isolated lecturer/subject level, while embedding graduate capabilities needs to occur at a program level with consistency and coherence in the development of these capabilities over the duration of the course. Moreover the goal needs to move from aligning to an institutional check list of general graduate capabilities to a response to engineering realities. The EGCC poster has been designed to represent this broader vision and provide a framework for implementing and monitoring it.

The project also observed that many curriculum reforms, such as the embedding of graduate attributes, would benefit from and indeed required a more rigorous and managed process of curriculum review. The process-overview poster was developed to provide a practical framework for doing this. It depicts eight stages of review with three overall themes governing all stages, and key questions to be asked for each of the stages and themes. While it is intended for engineers it is remarkably generic, and while it is derived from work by an earlier group it is not clear how deep into the generic literature its roots go.

The project team comprised 10 people. The report details that they went through a lot of learning, a great deal of which is exposed in several conference papers attached as appendices. This forms part of an extensive dissemination process through workshops and conferences, some international. The posters have been distributed widely and gained much positive feedback as a result.

The project mentions that curriculum developers see the embedding of generic attributes as a series of hurdles to be overcome rather than one insurmountable obstacle. It would be an interesting piece of further work to detail those hurdles and provide strategies for overcoming them.

Gender inclusive curriculum in engineering and construction management (CG8-696) (2008)

The project aims to provide principles, guidelines and exemplars that promote gender inclusivity in engineering education, and ameliorate a culture widely perceived and documented as inimical to the values of young women. The principles and guidelines appear in a booklet *Guidelines for the design of inclusive engineering education programs* along with faculty benchmarking guidelines for inclusivity. They advert to a book produced by the project, *Gender Inclusive Engineering Education*. The project ran workshops to disseminate its ideas and to begin lobbying for the adoption of its principles and guidelines in faculty course approval processes, university graduate outcome statements and Engineers Australia accreditation guidelines.

The curriculum principles that the project proposes are not particularly gender specific. Gender is subsumed in a broader inclusivity that advocates taking account of student diversity to the maximum possible, to be implemented, broadly speaking, by a constructivist approach to learning. The benchmarking guidelines for curriculum inclusivity therefore appear directed more at a shift in teaching ideology than a shift towards a gender neutral or female supportive culture.

The principles are meant to be practical. They include statements like ‘Enable every student to reach his or her potential’. In classes of 400 students this is not practical in any literal sense and the idea needs to be expanded with practical examples to give it meaning for engineers teaching large classes. Exemplars would have filled this gap, but the guidelines and the report are very sparse with these and refer the reader to the book.

A significant exemplar appears to have been missed in chemical and environmental engineering, which the report notes have strong representation by women. This is passed over because these subdisciplines are minor within the engineering cohort. But they must be doing something right and it would have been good to identify and exploit it more systematically.

Similarly it is difficult to find many specific examples of the differences between men and women that bear on engineering curriculum. One specific considers a continuum from teaching theory in isolation, to presenting it with industrial example, to the inclusion of social effects. The rationale behind this is so thinly drawn that it could be taken to be gender stereotyping men as isolated theorists and women as focused on social effects.

While those who are attune to gender discrimination would be able to flesh out this example, those who are not may well remain unconvinced. This may explain why the evaluation report found that the theoretical basis for gender inclusivity appeared not to be well understood.

The evaluation report found that the workshops did raise awareness of gender issues, and the report covers significant issues of the gender composition of staff and students in engineering faculties and why curriculum matters in addressing this.

Mathematics

Teaching and assessment of statistical thinking within and across disciplines, Helen MacGillivray (2006 ALTC Senior Fellow) (2006)

There has been a reform movement in statistics education for over 20 years. It advocates moving away from a narrow technical focus on statistical tests and calculations to statistical thinking – a broader analysis of data sets and methods acknowledging, among other things, the role of context of the data, the variety of phenomena that present themselves and the kinds of questions that can be asked and answered. The author is a well-established figure in this reform movement and gives a good brief overview of its broad issues and trends in section two of this report.

In advocating that students learn through experience of and modelling with authentic data sets, the reform makes strong contact with constructivist thinking and inclusive curriculum agendas. In some forms it appears as an attempt at an independent identity for statistics by playing down its connection with mathematics. However another interest in statistics education reform lies in the idea that it role models an agenda for mathematics more broadly: to become less narrowly technical and focus more on the contextual basis and ideas behind techniques. This also relates to the current interest in threshold concepts.

The fellowship report documents an intense year of activities that network among the like-minded nationally and internationally, advance and enrich ideas about statistical thinking, create a cadre of people to advance these ideas and hold conferences and forums to engage these ideas with students, teachers and the broader statistical community. The activities appear to have had a substantial national influence in raising the profile of statistics education and statistical thinking

Page 23 of the report provides a list of findings, of opinions and insights that the author has gained in the course of the fellowship. It goes on to list resources comprising journal articles, book chapters, conference proceedings, a DVD, a website and teaching materials available on request. However, while the report raises the issue of identifying and tackling significant and extensive challenges for statistics education reform, the report itself largely regards these as understood and says little that is analytical about them. To find out more the reader will need to turn to the resources mentioned above. They provide a rich tapestry of ideas and efforts, although they do not provide an analysis or summary review of precise issues and challenges for the advance of statistical thinking.

Technology

Improving the formative and summative assessment of novice computer programmers (PP6-48) (2006)

The project cites the lack of formative feedback to students in introductory programming classes as a major source of low student satisfaction and retention in computing courses. It identifies current forms of assessment, laboratory problems, assignments and end-of-semester exams, as largely summative and where manual marking for large classes leaves little room for formative feedback. It aims to make more widely available two existing online formative feedback systems to foster more experimentation in this area.

The Reflect system, developed at The University of Sydney, is an online environment providing a framework intended to allow students to build their reflective skills to assess their own learning. The project integrates the existing Reflect system into the Moodle learning management system, in the hope that this will enable a dramatic uptake of Reflect by educational institutions.

The skill building framework of Reflect is reviewed only tangentially in the course of describing the user interface of the integrated system produced. Its automated aspects appear to amount to short answer questions that are marked right or wrong, accompanied by a score and a statement explaining the right approach. There is also provision to submit text responses to questions that are marked by tutors offline. The exercises are linked to explicit learning objectives. However, the system is exemplified only for a course in management and group work, with the learning objectives abbreviated to something like topic names. How one approaches the issue of providing meaningful learning objectives and formative feedback with regard to programming skills is not addressed.

ELP (Environment for Learning to Program), developed at Queensland University of Technology, does address this point. It provides a problem-solving environment that presents programming problems accompanied by a template for their solution. Students enter code into text boxes within the template that contain a general description of what that code should achieve. The completed program can be run and a static analysis returned. Students can post questions and receive responses, like a chat session. Thus the software automates a well-known and valued learning approach, but the project is not about discussing its strengths and weaknesses, or what capacity building is required for teachers to use such an approach well.

Rather the project is to re-engineer the ELP software to operate in the manner of Wikipedia or Facebook, where programming exercises are shared learning objects that, along with all the software necessary for curation and processing, are accessed from a central server. Consequently students can operate the system from anywhere using only laptops or iPhones. Teachers can author exercises and manage feedback through the same interfaces, creating a flexible and widely accessible online system.

Linuxgym: a sustainable and easy-to-use automated developmental assessment tool for computer scripting skills (PP6-29) (2006)

Linuxgym is a software system that provides formative feedback to students on their Unix scripting skills. This report, however, should be of interest far more widely than to those concerned with this specialty. Scripting is a type of computer programming, a technical skill that requires judgement as to its application, a variety of competencies for its execution, and fair amount of practice and experience to achieve them. The report likens it to driving a car, but it could also be likened to using differential calculus or linear algebra, constructing spreadsheets, interpreting graphs, constructing sentences in a given language, interpreting a (mass) spectrum or interpreting the results of a BLAST search.

The weapon of choice for frequent and regular mass feedback is generally the short answer question. However, short answers are generally unable to achieve development of the judgement and competency required in technical subjects such as those above. The innovation of Linuxgym is to provide authentic formative feedback that does develop these attributes; a basically constructivist learning environment for them. It does so by running the scripts produced by students on hidden data sets and comparing key attributes of the output with those required of the script. The report likens this to a line manager drawing attention to a bug in someone's script. This approach also allows for multiple valid solutions, which is usually the case in reality.

In a world of computer algebra systems, automatic translators and automatic annotators of spectra and searches, it should be possible to do the same thing for a wide variety of technical skills. The development and introduction of Linuxgym at UTS led to a reduction of failure rates from over 35 per cent to under 10 per cent in undergraduate coding subjects and from 30–50 per cent to almost zero in one postgraduate subject. Failure rates in many technical subjects are very similar, and the prospect of similar success from a similar approach is very appealing.

The goal of the project was to make Linuxgym available across all institutions. This was in part a software engineering and software management exercise that was not as successful as the project leaders would have liked for reasons discussed in section three. However, of broader interest is the observation that a common uptake of the system requires a convergence of curriculum (in scripting) across institutions, and the idea that industry requirements could be a driver for it. Industry was surveyed about a list of scripting commands, for their views as to whether their use should be automatic, known but used occasionally, looked up in a manual or left to specialists. A similar analysis might be worthwhile in other technical areas.

Teaching novice computer programmers: bringing the scholarly approach to Australia – A report on the BRACElet project, Raymond Lister and Jenny Edwards (2007 ALTC Associate Fellows) (2007)

The interest in this report lies profoundly beyond teaching novice computer programmers. It espouses a scientific approach to teaching, it shows how this approach plays out in devising end-of-year exam questions that probe issues around levels of cognitive skill, and it shows how to make teachers' understanding of these ideas and capacity to use them grow over time via a collaborative and cross-institutional action research program.

The same ideas apply to many technical areas, not just computer programming, and appendix D distils the project's experience into tips for other disciplines who might want to follow them. This would be particularly valuable for disciplines involving quantitative skills, where university teachers have long lamented low progression and retention rates; the folklore blaming this on lack of preparation and/or native ability of students. The report connects explicitly with mathematics education in section 3.4.

Scientific teaching is a growing worldwide movement which advocates formulating precise, practical and testable ideas about student preparedness, capabilities, relevant teaching strategies, and refining ideas in light of the test results. Scientific teaching is to be contrasted with the more usual reliance on custom, practice and staff room speculation. The latter has been called folk teaching, drawing a parallel with modern medical research versus folk medicine. Many will find it a transformative experience to read the concise and compelling exposition of this contrast in the introduction to the report.

Equally transformative is the role modelling of the scientific teaching philosophy in the case of novice computer programmers. The project shows how it is possible to devise end-of-year examination questions to test cherished assumptions about why students are or are not capable of writing computer programs. In particular, the project seeks deeper explanations by constructing phenomena that are institution independent. This stands to eliminate a major folk variable for explaining student performance, namely quality, since this is thought not to be institution independent.

In section three the report describes the evolution in thinking over three years and five conferences, as the project participants follow the action research (many would say scientific) cycle of formulating ideas, devising exam questions that would test them, analysing the results of these exam questions and then refining their ideas. The appendices contain abstracts of papers arising from this work, and appendix C provides a technical summary of recent results for the ICT expert.

Ongoing ALTC projects and fellowships

(The year at the end of each title is the year in which the project or fellowship is funded. Project/fellowship titles are live links to the resources.)

Science

Quantitative skills in science: curriculum models for the future (PP10-1640) (2010)*

Lead institution
The University of Queensland

Partner institutions
James Cook University, University of Western Sydney, Purdue University (USA), University of Maryland, University of Maryland (USA)

Project leader
Ms Kelly Matthews

Project abstract
Numerous national and international reports have recently called for urgent actions to address the deteriorating quantitative skills (QS) and confidence of students at secondary and tertiary levels. This is particularly true in science, where such skills are essential for graduate competence and preparedness. Addressing the broad decline in QS will require substantial changes to science curricula, but individuals and institutions are struggling to understand how to best achieve this in practice.

This project will address the challenge, by: conducting international benchmarking of undergraduate science curriculum structures; identifying proven institutional curriculum change processes in national and international institutions; and developing a framework whereby interdisciplinary collaboration can take place in order to promote and nurture the development of QS in science students and curricula. A particular strength of this project is the active involvement of an impressive team, including presidents and executive members of a number of key stakeholder groups (such as FASTS, ICMI, MERGA, HERDSA and ACDS).

Program Priority
Curriculum renewal

Key words
Quantitative skills, science, mathematics, interdisciplinary, curriculum change

Scheduled completion
October 2012

Engineering

Assessing individual learning in teams: developing an assessment model for practice-based curricula in engineering (PP9-1380) (2009)*

Lead Institution
Central Queensland University

Partner Institutions
Aalborg University (Denmark), The University of Melbourne, Victoria University

Project Leader
Dr Prue Howard

Project Abstract
Grading individual students in teams has always been problematic. To accurately measure individual learning outcomes, students' grades need to be based on what they have learned as an individual, within the team context. Traditionally, individuals have been assigned a grade heavily influenced by the result of the team's project. Consequently, a poor team project results in poor grades for the team's members, even if significant individual learning occurs. As assessment drives behaviour, the desire for higher grades influences the team dynamics resulting in an emphasis on project outcomes rather than individual learning, potentially degrading collaborative learning.

This project aims to change significantly the Australian engineering discipline's understanding and acceptance of assessment of individual learning in teams by developing a valid assessment model to assess individual students' learning in a team environment, specifically in the context of project-based learning. The model will encourage students to learn from mistakes and failures, be creative and challenge themselves, and to develop reflection and self-assessment skills.

Program Priority
Academic standards, assessment practices and reporting

Key Words
Teams, assessment, PBL, project based learning, practice based, grading, portfolio

Scheduled Completion Date
January 2012

DYD: Defining Your Discipline to facilitate curriculum renewal in undergraduate programs (PP9-1280) (2009)*

Lead Institution
University of Southern Queensland

Partner Institution
University of Tasmania

Project Leader
Professor David Dowling

Project Abstract
The project will develop an efficient, effective, and inclusive consultation process, the Defining your Discipline (DYD) process, which may be used by discipline stakeholders to define practitioner-authenticated graduate outcomes for their discipline.

The two-year project has five stages.
1. The project team will review the literature and consult widely to develop potential DYD processes.
2. A DYD process will be used to consult the stakeholders in a smaller engineering discipline and develop a set of draft graduate outcomes that are specific to that discipline. These will expand on the generic graduate attribute statements defined for all engineering disciplines.
3. The DYD process will be reviewed and refined, and the project will be formatively evaluated, culminating in a mid-term report.
4. The DYD process will be used to develop a set of overlapping graduate outcomes for one of the larger engineering disciplines.
5. The DYD process, and associated documentation, will be published and made available for use by other disciplines and professions.

Program Priority
Curriculum renewal

Key Words
Graduate attributes, graduate outcomes, stakeholder consultation, curriculum renewal, accreditation

Scheduled Completion Date
January 2012

Conclusion

The projects reviewed in this report address a variety of issues in teaching and learning. Several are notable for their depth of approach and potential to make an impact. Three of the five biosciences projects are in this group, the BioAssess project (PP5-32), the Inquiry skills project (CG8-763) and the Online assessment feedback project (PP5-41).

All three locate an analytical framework for their ideas in established educational literature, rather than confine themselves to discipline custom and practice, or attempt to evolve ideas out of it de novo. The BioAssess and Inquiry skills projects set about engaging academic staff in the ideas identified by encouraging them to contribute good practice examples. They also had clear general engagement and dissemination strategies, BioAssess through its website and roadshows, and Inquiry skills through its project handbook distributed to all universities.

The Online assessment feedback project pinned its dissemination hopes on the high risk strategy of embedding its ideas in a software platform, which didn’t materialise as the project had hoped. Nonetheless, its conceptual framework, use of clearly articulated principles of formative feedback, and development of a style guide for the provision of feedback, provide an inspirational and transformative model for anyone who wants to investigate the use of automated formative feedback.

These projects raise a critical issue for any organization like the ALTC, committed to promoting change and innovation in university education. All three provide well-articulated ideas on improved practice in the issues that they address and in their various ways provide convincing ‘how to’ material for their implementation. However, change will only occur when these ideas are mainstreamed into faculty teaching and learning processes. The conceptual frameworks and ‘how to’ material provide exactly the kind of tools needed for deans and their associate deans teaching and learning to establish, monitor and encourage the ideas that these projects promote. No other projects arrive at such a strong position of having the essential elements to generate systematic change. However, this final step of organizational engagement remains to be taken, and the ALTC should consider projects that would support this step.

The project Tertiary Science Education in the 21st Century (DS6-596) bears profoundly on this matter. It is a study of the organizational and workforce culture that supports the delivery of first year science laboratory classes. It found a disturbing inability on the part of all involved to articulate the role and rationale of first year laboratory classes, particularly in relation to the diversity of students involved, despite that academic scientists hold up laboratory work as essential to learning science. It also found no serious engagement of the demonstrator workforce in professional development, and in teaching and learning issues.

Rarely did the experimental programs live up to the idea that they provide a different learning environment which is more ‘hands-on’, student-driven and therefore more engaging, or even that they co-ordinate with lecture material to provide practical enlightenment to theoretical ideas. If faculty organisation is not able to project the conventional ideology about laboratory classes then it can hardly be expected to function well as a vehicle for new ideas about teaching and learning. Laboratory classes are but one aspect of the organisational culture of STEM teaching and learning. It would be well worth undertaking studies of other aspects of this culture so that the real challenges of promoting change could be understood, and ideas for change developed that could work productively in that culture. The project was aimed at deans and their associate deans teaching and learning, with recommendations for their action.

The BRACElet project is notable for its development of a community of practice that adopts a scientific approach to the construction and interpretation of end of year examination questions on computer programming. Some thought could be given to supporting the establishment of similar communities of practice in other STEM disciplines. The interest lies in the assessment of technical skills and the interpretation of assessment outcomes in terms of levels of cognitive ability, an approach which would yield considerable insight in areas such as mathematics and physics where students' lack of technical proficiency is a source of high failure rates and constant lament. It is not clear, however, how one would make such communities sustainable or how to make their insights impact on the main stream.

The Linuxgym project (PP6-29) provides a classic example of innovative work with the potential for wide impact that disappears with its originator. This is, regrettably, the fate of the greater number of projects on teaching and learning. The Linuxgym project shares the approach of a number of others reviewed here, that attempting to propagate their ideas by developing a software platform available to all universities. There are now enough examples of this approach to show clearly that it is a high risk and very complex path. It needs to be managed as a software engineering project to produce the platform alongside a marketing and customer engagement program for its dissemination. Often this evolves into significant commercialisation issues that have not been considered upfront, not to mention institutional barriers to adoption arising from existing choices of software systems.

Notwithstanding these aspects, the Linuxgym project adverts to the potential for technical software platforms to deliver automated high quality formative feedback on the development of the technical skills that they embody. Technical skill development requires constant practice and frequent feedback that reflects on the ideas involved and improves students' judgements about whether they are applying these ideas properly and appropriately. Linuxgym considers this in the case of 'scripting', which is programming in Unix. It uses the fact that students submit their program to a computer which then parses their program to convert it into executable machine code. By breaking into this automated analysis one can also have the computer deliver high quality diagnoses as to where a human may have gone wrong. Students can thereby gain immediate automated feedback on their work as often as they care to submit it.

These days there are software platforms in mathematics, engineering, chemistry, areas of physics and in genomics that accept problem input, parse it and carry out technical calculations and tasks automatically. These platforms make their corresponding subjects ripe for the same treatment of the technical skills that they involve, as Linuxgym makes of programming. So while on the one hand science teaching is trying to introduce more problem and context based approaches to bring out a vision of science in contrast to its narrow technicalities, there is also an opportunity to revolutionise the teaching of these technicalities through automated high level formative feedback. It is an area to be much encouraged in future projects.

The immersive virtual reality project in chemical process engineering (CG6-21) provides important new insights into the role that such systems can play, not just in substituting for onsite experience, but in the new collaborative industry relationships that are possible. The one-page review indicates the wide range of teaching and learning situations to which these ideas could apply.

Recommendations

Recommendation 1

The BioAssess website be redeveloped and renamed as a site concerning best practice for STEM assessment generally. The BioAssess 'front pages', which provide a narrative on assessment generally, should be restructured so that projects from other disciplines can link into them in the same way the biology best practice examples and other biology materials currently do.

Recommendation 2

The BioAssess project be replicated for other disciplines, particularly chemistry, physics, mathematics and any others that have a major role in foundational and service teaching for STEM courses. These replications should not be independent but should link to the redeveloped BioAssess project and its website as per Recommendation 1.

Recommendation 3

The approach to automated formative feedback described in **Online assessment feedback as an instrument of reflective learning practice in Human Biology** be replicated through projects in other major disciplines and across biology more broadly. In particular projects should acknowledge and address the guidelines for the development of feedback responses identified in this project, or some variant of them which includes a basis in principles, eg the FAST 11 principles of effective formative feedback, analyses of error patterns and their relation to student characteristics, and developing student capability for recognising and responding to feedback.

Recommendation 4

Projects be encouraged that take up the approach of Linuxgym for providing automated formative feedback in the development of technical skills. The projects should also adopt the principles and ideas of Recommendation 3. This recommendation concerns technical skills that have been embedded in software platforms. The same software can be tapped into or mirrored to deliver diagnoses as to where a human may have got these techniques wrong and why. Many STEM disciplines, particularly mathematics, physics and chemistry, have the same opportunity as the Linuxgym project, to use their software tools of trade as the basis to deliver high quality formative feedback.

Recommendation 5

The project **Enhancing the learning of scientific inquiry skills for bioscience students** be replicated across chemistry and physics. Such projects should pay particular attention to developing an evidence base for the effectiveness of their methods, and link to the work of ASELL with regard to their laboratory components.

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