CULTURAL REFORM IN SCIENCE EDUCATION

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Summary: It is apparent that higher education in science and technology requires urgent reform to redress the declining number of career scientists and ensure they are internationally competitive. Education programs need to revise curricula with all stakeholders to offer tailored courses for specific student streams. Academics must move from traditional transmissivism to modern constructivism models of education by adopting small group tuition, practical instruction and discovery-based learning to optimize learning outcomes. This will involve significant cultural changes within universities. All academic career paths must include and value teaching components, compulsory teacher training programs must be instituted to improve quality, and the growing gulf between teaching and research activities must be bridged to afford scholarship.

INTRODUCTION

I have long reflected on the need for cultural reform in science education to better prepare students for vocational demands not only for their scientific knowledge and technical competencies but also for their cognitive and metacognitive faculties. Universities need to emphasize training in scientific thinking (habits of mind) just as much as in scientific knowledge (theoretical and applied). While my views on the current situation are idiosyncratic, I do not seek to provoke controversy, but rather, to simply give a personal and reflective account as I see it from the coalface - that is, from the front of the classroom. It is my contention that we can teach science and scientists much better: more methodically; more systematically; and more scientifically.

The 'scientific method' is based on hypothetico-deductive logic, experimentation, critical interpretation and reproducibility. Scientists are trained to be innovative, honest, precise, rigorous and critical. However, the training and attributes we look for in scientists are not always evident in science education programs. Science courses at universities are mostly content-rich and process-poor, teacher-centred rather than student-centred, atomistic in detail rather than holistic in conception, and long on theory and short on practice. While they may make use of modern information technology and multi-media modalities, they do not incorporate contemporary teaching and learning research demonstrating the benefits of social constructivist educational models (where students construct meaning) over traditional transmissivism models (where teachers transmit knowledge). How then can we get intelligent forward-thinking responsible scientists to apply the same logic and values to their teaching as they do to their research? We need to change the university teaching culture!

Much can be done to improve science education at universities. There are obvious benefits in regular curriculum review, tailored teaching, team teaching, interdisciplinary courses, providing vocational context, rewarding quality, mapping graduate attributes, defining learning outcomes, etc. For me, the most important challenges for science education over the next decade will be process-based rather than content-based, not what we teach but how we teach! The economic ramifications will be considerable, not only in terms of expenditure (the cost of educating scientists), but also in terms of income (their subsequent contribution to socio-economic growth). Universities are professed to fulfil three main functions: to act as living repositories of accumulated knowledge; to pass on this knowledge to the younger generation; and to add to the sum total of knowledge through research. We must become as diligent in our educational mission as we have with our research functions. I believe tertiary science education programs must:

- provoke change (update content, adopt contemporary teaching and learning practices);
- institutionalize teacher training (provide lecturers with educational skills);
- teach students in small groups (foster social interactive learning);
- provide practical instruction (promote scientific methodology and discovery-based learning);
- better value teaching functions (in academic career paths and research outcomes); and
- identify major student streams (tailor programs for different clients).

PERSPECTIVE

My view of academic life is obviously influenced by my background and experiences. I am a preclinical scientist currently teaching foundational biology and vocational microbiology at The University of Queensland. I joined the University 15 years ago after 20 years of public service as a diagnostician and researcher in medical and veterinary science. As a public servant, I was constantly participating in personal and professional development training programs to keep apace with the changing requirements of my employment. Change was viewed as part of the normal growth process and staff engaged proactively in review and development. When I arrived at the University of Queensland, I was regarded as an ‘outsider’ as most previous appointments had been ‘insider’ placements of postdoctoral staff. I considered this status to confer an advantage as I was able to bring a different perspective to the workplace. I became an advocate for organizational and teaching reform but such attitudes were viewed by peers as radical and hostile. Personally, I found many academics to have limited training as teachers (if any), to be insular and lacking in interdisciplinary perspectives and vocational context, to be paternalistic and highly opinionated, and to demonstrate considerable economic and political rivalry rather than academic collegiality. The pervasive climate of resistance to change was phenomenal and I was continually reminded that “If it ain’t broke, don’t fix it!” Such an attitude depends on your perspective and many things appeared broke to me. Growth is essential to healthy vital life (biological, intellectual, economic or organizational) and growth always involves change. It is better to prospectively embrace change rather that to have is forced on you retrospectively.

PROVOKE CHANGE

Change is inherent in science and we are entering an exciting phase in biology. New organisms are being discovered, cell life and death are being explored, and unique molecules are being synthesized. In the history of the Earth, most scientists are currently alive today. Advances to our knowledge are being made with regular frequency so it is natural that science changes with time. Boundaries between traditional disciplines have become blurred as common technologies emerge. Scientists working on organisms in the 1970s moved to cell biology in the 80s and molecular biology in the 90s. This transition has been spectacular. More than ever, students must understand molecular processes that underpin life sciences, biomedical research and biotechnological applications. Our approach to biology has also changed: early descriptive studies identified organisms; experimental and analytical studies then examined smaller components; integrative studies have recently attempted to reconstruct the ‘big picture’; and contemporary studies are now entering a new descriptive phase - this time aimed at molecules. Molecular biology has become fundamental to our probing of science. Microbes are being manipulated, genes are being sequenced, and organisms are being cloned. Indeed, many genome projects are nearing completion, thereby signalling the dawn of proteomics - studies on gene products.

Science is constantly changing as research progresses our understanding. By training, scientists are methodical creatures so it is paradoxical to me that they do not apply the same logic to science teaching. Pedagogy is defined as the science of teaching, yet many science teachers are unaware of pedagogical advances. Is this protectionism (maintain status quo/comfort-zone), paternalism (academic knows best, good enough for me), ignorance (no alternatives, limited experience) or laziness (no time, no reason, worked last year)? Scientists are very good at defining content, often doing so in exasperating detail within their area of expertise. However, it is often done in an intuitive fashion which is not transparent to others. They acknowledge that scientific knowledge is advancing at an unprecedented pace and that courses must be constantly updated to remain contemporary and relevant. Curiously, only the stalwarts can produce evidence of regular revision of course materials each semester and most changes are often done in minimalist fashion. Nevertheless, most academics cite active participation in regular curriculum review and course development in their annual appraisal documents. Few get around to defining what they mean by curriculum. Educationalists define ‘curriculum’ as relating to the ‘content’ and ‘purpose’ of an educational program, together with its ‘organization’. Most scientists will happily revise course content, a few brave souls may suggest re-organization (usually limited in scope due to financial constraints perceived to be beyond their control), but most gloss over the underlying purpose for the program (apparently comfortable that the course fits within a generalist degree). How do we ensure that the *raison d’etre* for science courses complies with all stakeholders expectations?

Who actually sets the curriculum? Surely it is the collective wisdom of many parties with vested interests, both internal and external to the university. Consultations must be held with relevant professional, industrial, governmental and educational agencies to demonstrate relevance, application and utility of courses, alignment with prospective employment, society need and community benefit. Teachers like to think they set the curriculum, administrators review and restructure, government and industry strategize over employment and labour markets, social commentators voice community concerns, economists attempt to balance supply and demand, and students vote with their feet selecting popular courses. The latter can be dangerous as students often have idealistic notions about particular careers and become disillusioned when reality does not live up to expectation (e.g. television dramas have recently popularized forensic science but there are few employment opportunities). The media strongly influences community perceptions of scientists which are portrayed as everything from mad professors to dedicated humanitarians. Community acceptance and social rank strongly influence career choices by students and these differ markedly on a regional basis. Course offerings at universities must take into account many diverse views and opinions and wants and needs. Many stakeholders recognize the need for educational reform, especially in science, engineering and technology. Higher education in Australia is indeed undergoing a period of reform, addressing the criteria of quality, equity, diversity and sustainability. Curriculum review should be entrenched in all courses and programs in modern universities. Client demands and perceptions vary with time and changes must be planned, resourced and actioned.

Over the last four decades, The University of Queensland has nurtured its reputation as a research-intensive university. Faculties recruited academic staff with strong research performance in specific disciplines. This was conducive to the formation of boutique departments, some being small and having light teaching loads. More recently, economic rationalization and a competitive marketplace has led many Faculties to review their operations and restructure; in particular, to identify core activities and allocate resources accordingly. In the Science Faculty, 12 Departments were progressively amalgamated into four Schools. Many lamented such changes and predicted that the fiscal dissolution of conventional disciplines would significantly diminish the science program. Instead, the program received a much-needed overhaul: disciplines had to realign with contemporary practice as boundaries had become blurred. New interdisciplinary courses were created as fundamental conceptions and technologies were identified. It was also time for some disciplines to move on. The reasons for their creation many years ago had changed substantially and it was time to take stock of the present situation and implement change.

My Faculty implemented a rolling reform of all undergraduate courses. The rationale for change was to better utilize finite resources, reduce wastage, promote areas of strength, and support staff during workload intensification. Faculty reduced the number of courses offered by 40%, developed programs and course plans in consultation with prospective employers, and encouraged staff development activities. It was determined that most traditional, and many emergent, scientific disciplines could be based on a selection of foundational courses with overlapping boundaries and shared technologies. This fostered interdisciplinary collaboration which was also perceived to be vital for the establishment of centres of excellence. Core courses were introduced at junior levels and multidisciplinary fields of study (including dual majors) were encouraged at senior levels. This process of change is ongoing. First pass solutions were not always appropriate and courses always need to be updated and refined. However, most changes are occurring at the level of scientific content and do not explicitly address teaching and learning methodologies. We need to adopt better teaching practices using contemporary educational models to identify and link course content, delivery and assessment. Before we can begin to properly address science teaching reform, we need to educate our teaching staff into educational theory and practice as most are blissfully unaware of basic principles and techniques. We need to train our teachers.

INSTITUTIONALIZE TRAINING

As a newcomer to tertiary education, I was awed by the academic freedom afforded lecturers but dismayed by the apparent lack of organization of educational resources and the quality of delivery. Of course, my observations only relate to those courses with which I was involved and there were always exceptions to the rule; for instance, there were some outstanding lecturers and several well-organized courses; but overall the standard was low. In a society where universities are at the apex of the education pyramid, I found it paradoxical that teaching models and methods were better understood by primary and secondary school teachers than by most university teachers. School teachers must have essential qualifications to teach, these days being a dual degree (BEd slowly replacing DipEd). However, in most university Faculties, tertiary teachers do not need any formal qualifications to teach. It seems to me that we are denying academics the most elementary tools of the trade. If we are to employ contemporary educational models within our undergraduate and postgraduate courses; why not use similar processes to provide vocational or continuing education for academics? We need to provide academics with essential teaching skills, change their attitudes from teacher-centred to student-centred to facilitate deep rather than rote learning, establish fundamental educational conceptions and provide knowledge of best practice.

Lecturers are generally recruited on the basis of their research performance and while most possess good presentation skills, they usually do not have any formal training as teachers. Scientists tend to focus on course content and teaching issues more than on effective student learning. They need to retool and adopt better teaching and learning practices to ensure quality of product. How do you entrench teacher training into universities? Many universities promise to “spend the money as it’s earned” but not all teaching income finds it way back to teaching activities. Universities do fund staff development initiatives involving action learning projects, staff induction programs, information technology (IT) and multimedia workshops, and teaching and learning conferences. Various mechanisms for providing informal training are also being explored, including the concepts of mentoring junior staff, peer feedback through buddy systems, forming teaching teams and running specialty workshops. The major problem encountered has been poor staff motivation and participation. Voluntary attendance does not access the staff that would benefit most from training programs. Perhaps it is time we seriously consider formal qualifications for tertiary teachers at the certificate, diploma or degree level. Quality could only improve as we teach teachers how to teach. Sadly, most suggestions to institutionalize teacher training are met with alarm and concern about workload intensification, diminished intellectual freedom and restrictive work practices. Improving teaching quality will necessitate workplace reform to get staff to accept formal educational qualifications as an essential (rather than desirable) prerequisite to teaching at university level.

What do you teach academics about educational theory and practice? Once again, I believe the emphasis should be on process rather than content. We can espouse theories, invoke jargon, consider models, collect data, analyse options, compare results, map attributes and identify outcomes. But really, there is no single solution to any particular teaching and learning problem. I believe it is about giving academics choices, giving them enough information so they can try out different ideas, select appropriate models and adopt best practice. The greatest mental challenge for academics is to realize it is not about them, it is about the students. The emphasis must be on effective learning. Learning has been categorized within three major educational domains; cognitive (about knowing), affective (about feeling) and psychomotor (about doing). Six categories are recognized in the cognitive domain (knowledge, comprehension, application, analysis, synthesis and evaluation) and five in the affective domain (receiving, responding, valuing, organizing and characterizing). While no formal categories have yet been proposed in the psychomotor domain, generic learning behaviours, manipulative skills and technical competencies have been identified as desirable. Students generally switch off when such jargonized psycho-babble is introduced into course outlines, but they quickly assimilate user-friendly versions. Many courses now explicitly state learning outcomes using the SACK acronym which differentiates between Skills, Attitudes, Concepts and Knowledge.

A variety of models are also available for curriculum development (objectives versus process models), providing instruction (scope, sequence, schedule models), conducting assessment (measurement and standards models), undertaking evaluation (intuitive versus systematic approaches) and performing educational research (process, product, learning and causal paradigms). Curricula must be defined in relation to action: five recognized categories being: envisioned; developed; enacted; assessed; and learned. What we set out to do and what the students learn can be entirely different things. The translation of curriculum from theory (planning) to practice (operation) involves interactions between many component parts, including instruction, assessment and evaluation. Different relationships between curriculum and instruction have been described in dualistic, interlocking, concentric, cyclical and spiral models whereby content and action exhibit no, partial, total, continuous or periodic dependence respectively. Integrative approaches have recently been taken a step further with the formulation of constructive alignment models which link curriculum, instruction and assessment. Curriculum objectives are defined in clear measurable terms, instructional activities are chosen to realize those objectives, and assessment criteria and standards address specific objectives. The use of such models in teaching and learning makes the system transparent to both teachers and students and fosters engagement and reflection. Alignment models have previously been used in physical, biological and earth science curriculum development, including the FAST model (Foundational Approaches in Science Teaching) aligning interdisciplinary foundational concepts and methodologies with formal and informal evaluation mechanisms.

While scientists concentrate on content and teachers on process, students focus on assessment. It has long been recognized that assessment drives learning. In the past, heavy emphasis has been placed on summative assessment tasks to measure learning rather that formative assessment to support learning. Assessment has traditionally been facilitated by ‘measurement’ models which rate individual performance against population normal distributions rather than by ‘standards’ models which criterion-reference higher cognitive level performances. We should always endeavour to assess for understanding and this involves defining what we mean by ‘understanding’. Bloom recognizes five hierarchical levels of understanding: pre-structural; uni-structural; multi-structural; relational; and extended abstract. Desirable learning outcomes should involve higher order understanding and assessment tools should evaluate cognitive, metacognitive and social competencies and affective dispositions. Students are not well versed in educational paradigms so it is important they come to understand the process. We need to translate educational jargon and explain teaching and learning models so they appreciate program and course design. When students understand educational processes, they participate and become active learners rather than passive recipients. Engagement empowers students, facilitates self-determination, engenders ownership, generates enthusiasm and stimulates feedback on process, content and delivery. Ramsden lists six key principles for effective teaching in higher education: clear goals and intellectual challenge; interest and explanation; concern and respect for student learning; appropriate assessment and feedback; independence and active engagement; and learning from students.

Academics need to make informed choices about their teaching modalities and concentrate on what best supports effective student learning. Scientists can learn a lot from other educational programs, particularly those in liberal arts degrees which rely more heavily on social discourse with, and amongst, students. There is little argument that the most effective learning occurs in small socially-interactive groups.

SMALL GROUP TEACHING

Educational research has shown that there are many tangible benefits from small group teaching. It can provide vocational context and model professional life. Public perceptions of science and technology are changing and scientists play a greater role in society than ever before. Teachers must show course relevance to contemporary science and technology, vocations, employers and communities. This involves changing teaching paradigms to better model workplace practices. Increasingly, students are involved in problem-based or case-based learning, industry projects and even industry placement. These modalities involve small-group teaching, contextual learning and fostering self-directed learning (SDL) through a process of directed self-learning (DSL). We are shifting from transmissivism to constructivism models where students construct meaning individually, socially and communally. A range of teaching modalities are used within university courses (lectures, tutorials, discussion groups, demonstrations, practical laboratory sessions), but they appear to be more dependent on resources issues (staff numbers, experience, funding, classroom configuration, information technology services) than on pedagogical logic (what’s best for student learning). By default, lectures have become the most recognizable platform for university teaching. However, scientists stating fact after fact in didactic lectures to large student groups does not guarantee learning or understanding. The best learning occurs outside lectures when students get the opportunity to question, challenge and make sense of information. Tutorials played a very important role in my education but they are now virtually absent in many science courses. Where then do students get the opportunity to validate their learning through discussion?

It would be nice to think that students indulge in collegial peer discussions similar to those associated with the coffee club cultures in universities a century ago. However, with many science courses on offer, students in individual courses usually do not know each other and they rarely meet out-of-session to consider course material. I often walk through student common areas and observe numerous students sitting around, most by themselves. Students in science courses usually do not form strong peer networks unless introductions and agendas are facilitated through formal sessions. In contrast, students in professional courses (such as medicine or veterinary science) form strong cohort bonds as they all take the same courses and have social functions to get to know each other. How can we provide similar opportunities for science students? It is abundantly clear that they require supplemental instruction to come to grips with the voluminous material that confronts them. Ideally, extra tuition should be tailored for individual students to provide a personalized approach to their educational needs.

An innovative solution has been trialled at this university with the creation of PASS groups (peer-assisted study sessions). Rather than provide tutorials run by academics (who often act as intimidating content experts), a system of voluntarily-attended PASS groups was introduced (peer-assisted to ensure that learning was student-directed and student-centred). The PASS paradigm epitomizes the social constructivism model of education whereby small groups of students meet and interact to construct meaning. Participating students develop and enhance many qualities, including philosophic, psychologic, metacognitive, cognitive, social, and personal skills. The objective is not just to make better scientists but also to make better people. Small group teaching and learning personalizes the educational experience which counteracts the impersonal nature of large classes in large universities. Regular meetings with small groups also eases the transition of students from school to university and gives them the ability to develop friendships and networks with fellow students. It builds student confidence, self-assurance and promotes interpersonal skills and social interaction. Peer facilitation of the group is mandatory to provide a non-threatening social and intellectual environment in which the students can admit ignorance and misconceptions and seek information, advice and remediation. The PASS structure is a three-tiered system whereby academics direct PASS leaders in knowledge processing and learning strategies thereby making them apprentice teachers. PASS students view participation as a value-added experience to their education at university.

In addition to peer networks, many courses now employ problem-based learning (PBL) paradigms to promote student participation and communication, provide vocational relevance and problem-solving skills, foster holistic and interdisciplinary perspectives, and engender critical thinking. In its simplest form, PBL provides small group teaching and learning experiences centred on a series of problems which the students address systematically. They must activate their prior knowledge, critically evaluate that knowledge, develop relevant learning objectives and lines of inquiry to acquire new pertinent knowledge and apply it to the problem. PBL is merely a vehicle for students to identify what they already know, what they do not know, what they need to know, how to get it and what to do with it. PBL allows students to develop thinking and reasoning abilities (such as problem-solving and critical thinking) as well as facilitates learning management (self-directed life-long learning skills). PBL does not completely replace conventional forms of teaching, but complements fixed resource sessions and facilitates the integration of knowledge and skills from cognate disciplines. It has found a role in many university faculties, especially those graduate schools catering for professional vocations. PBL can be used to mimic workplace practices thereby providing realistic vocational context to training programs.

Obviously, small-group teaching does have heavy resource implications in terms of personnel, financial and physical resources. More staff are required to run small student groups, more money is required to pay staff, and more small rooms are required for student meetings. I believe governments and universities must be progressive to afford and facilitate quality higher education if we are ever to meet our own ‘smart-state’ and ‘clever-country’ rhetoric. Extra funding has been made available for IT services in universities and many programs announce with pride that IT is opening up the classrooms, allowing a shift from fixed classes to flexible delivery and distance education. In today’s society, students are surrounded by slick IT presentations of all things commercial. How can they expect anything less in the classroom? However, IT does not replace teacher-student instruction, it merely provides valuable tools for science education. It really does not matter whether students experience boring ‘chalk-n-talk’ lectures or colourful ‘show-n-tell’ multimedia presentations if the message is quickly forgotten. Students need time to contemplate information, reflect on meaning and test understanding before it is assimilated. In science, students often experience information overload, not only from their courses but also from daily life in our IT-endowed society. Being presented with detail after detail leads to surface learning where knowledge is atomistic, isolated, elicits limited understanding and is quickly forgotten. Universities must yearn for deep learning where knowledge is holistic, relational, facilitates good understanding, is remembered and applied. The best way to do this is through small group instruction and discussion. Human-to-human interaction provides the most effective teaching and learning experiences and outcomes. However, what types of learning processes are most beneficial for science students? Should students memorize science or discover it?

DISCOVERY BASED LEARNING

Numerous factors impact on student learning patterns and any discourse on those thought to be most pertinent to science education usually begin with a disclaimer stating that every situation is different. Nonetheless, educational theorists have moved from traditional theory-practice models through objectives models (where outcomes are prescribed or described) to process models (engendering active and discovery learning). Currently, there are strong pedagogic trends towards discovery- and inquiry-based learning, especially in science, engineering and technology. There are many dimensions to learning by discovery. Learning can be an outcome of novel experience, an expression of curiosity, reflection on a problem, analysis of an experiment, a moment of insight or invention rather than compliance to prescribed procedures, rote memory and regurgitation of isolated facts. Active learning and discovery-based learning are said to develop habits of mind that drive science. Process is valued as well as content. Students are encouraged to develop effective communication, master analytical thinking, participate in productive teamwork and be responsible for independent learning and resource utilization.

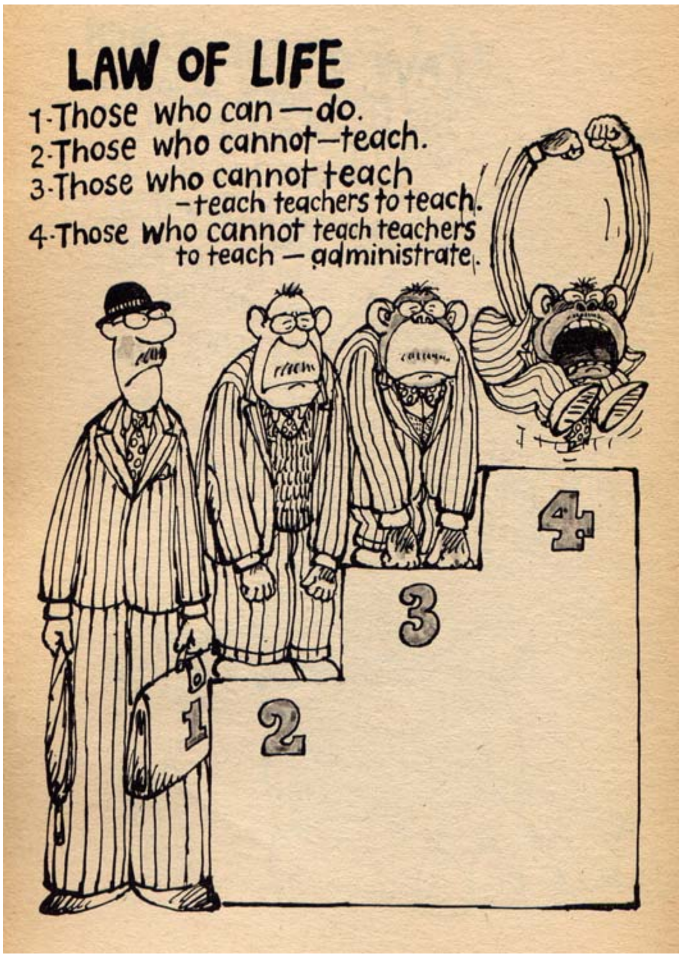
Many Universities have given considerable thought to desirable graduate outcomes and have adopted curriculum mapping exercises where outcomes are explicitly stated in courses and linked to relevant instruction and assessment. Courses must address generic skills required by all scientists, such as hypothetico-deductive logic, critical thought, ethical and social understanding. Specific knowledge of particular disciplines is better valued when it is based on strong fundamental conceptions and is integrative knowledge showing interdisciplinary perspectives. Science courses have also been criticized for reducing or doing away with practical components. In biology, laboratory sessions are essential to practice not only psychomotor skills and competencies but also cognitive processes. Practicals should be task oriented where students can obtain and practice descriptive skills (qualitative data), analytical skills (quantitative data) and interpretive skills (scientific logic or clinical reasoning). Practicals should be real experiences with unpredictable outcomes rather than simple procedural cook-books leading to specified results. This is important for two reasons: it provides first-hand evidence to students that science is not stagnant or cast in concrete but is vital and ever-changing; and it also forces them to process failure as not every experiment works due to flaws in design or execution. Students need to develop metacognitive skills to assimilate information, reflect on meaning and decide on future action. Such outcomes are not unique to science or the scientific method but are lifelong skills applicable to personal, professional and social behaviours.

The implementation of different teaching and learning paradigms in science education should be approached scientifically with the same vigour and rigour as scientific research. Changes must not be *ad hoc* or whimsical but based on strong comparative evidence for better outcomes. Many institutions are now commissioning reports on the future of science education and several recurrent themes have emerged. These are exemplified by some of the recommendations recently published in the Boyer Report of the Carnegie Foundation for improving undergraduate education:

- make research-based learning the standard;
- construct an inquiry-based freshman year;
- remove barriers to interdisciplinary education;
- link communication skills and coursework;
- culminate with capstone experience;
- cultivate a sense of community; and
- change the faculty reward system.

VALUING TEACHING

How are teachers valued in universities and communities? Idealists hold them as custodians of the intellects of future generations, critics regard them as having easy jobs with short hours and long vacations. Academic staff in modern comprehensive universities are composite creatures; they are expected to engage in teaching, research and service duties. It is often difficult to differentiate between these duties as considerable overlap can occur and many synergies exist between them. Research complements teaching by providing contemporary information, vocational context, technical skills, problem-based and self-directed learning experiences. Teaching complements research through increased awareness, aptitude testing, student streaming, and postgraduate supervision. Service provided to university and profession often involves membership of management committees providing teaching and/or research infrastructural support. I am disconcerted by the value system entrenched in academic life; exemplified by the attached cartoon. This apparently epitomizes academic evolution from valued researcher to burnt-out teacher (only superseded by maligned administrator).



Career advancement for modern academics has certainly become dependent on research performance. Numerous parameters have been developed to appraise staff performance in scholarly research. The two key indices used are ‘grants-in’ and ‘papers-out’. Objective measures of quality (such as journal impact factors and citation indices) are now being used to complement traditional subjective peer review processes used by granting agencies, publishing houses and employers. The current funding climate also favours collaborative programs with the formal creation of industry linkages, research networks, centres and institutes. These collaborative network approaches to science usually involve workload intensification through management by committee which requires greater bureaucratic support. Staff receiving substantial research incomes are given partial or whole teaching relief in their workload allocations, sometimes funded by the granting agency but often by the host university. Surely this sends the message that research is better valued than teaching and that they are two separate entities. Over the last decade, teaching performance has become better recognized within academic portfolios. Various teaching parameters are considered, the foremost being feedback from students using various instruments of evaluation (usually questionnaires). However, student perceptions of teaching do not always mean that effective learning has occurred. We need to develop better mechanisms to assess teaching quality other than to run popularity contests. The results are also often confidential to the teacher. Managers only see edited versions when staff apply for continuing appointment, promotion or annual salary increment. Feedback is pointless unless it is acted upon and this involves sharing information. Progressive curriculum and course development involves stakeholder meetings, focus groups and workshops where real data is presented and discussed. Many Faculties now conduct teaching quality audits where a percentage of their budget depends on successfully addressing certain criteria. National and international benchmarking programs have also been established to consider quality outcomes besides quantitative data on graduands and grants.

What can be done to improve teaching quality? Regrettably, training programs are resisted and often resented by staff, particularly those most in need. Many academics are apathetic or outright antagonistic to teaching reform. Any attempt to change allegedly impinges on their expertise or academic freedom. Collegiality is not widespread and petty issues dominate. How do you then institute change? Methods to improve quality must progress beyond reward and punishment. There are various local and national awards for teaching excellence. While such rewards acknowledge effort and performance, they are regarded as elitist without tangible benefits for everyone. Punishment and penalties are counter-productive and are contrary to workplace agreements except where breaches of law and professional conduct occur. Withholding increments and erecting barriers to career advancement are inappropriate and open to abuse by hostile managers. There is a growing trend to abolish tenure and introduce contractual employment where renewed appointment is dependent on satisfactory performance. The problem arises as to what constitutes satisfactory performance and who decides? At least we are now beginning to consider such issues.

Many governments have recently introduced reform initiatives in science education and research. The National Science Foundation in the USA has embarked on a mission to integrate research and teaching by formally linking both in grant applications and providing incentive funding. The Australian government has provided funding for teaching and learning through its Backing Australia’s Ability scheme by establishing a National Institute for Learning and Teaching in Higher Education, increasing the value of the Australian Awards for University Teaching and creating a Learning and Teaching Performance Fund to reward institutions that best demonstrate excellence. Research performance is rewarded through the Institutional Grants Scheme and the Research Training Scheme which are based on indicators comprising research income, student numbers and research publications. It is apparent that the dichotomous funding formulae need to be reconciled to create a nexus, rather than a gulf, between teaching and research functions integral to all universities. We in grave danger of separating these functions into teaching departments and research institutes which will only serve to further fragment academic life, reduce quality outcomes and alienate staff. The government has reaffirmed its intention not to create teaching-only universities while at the same time preferentially funding research-only academics. Where do students fit in this volatile tertiary environment?

STREAMING STUDENTS

Science education should be perceived as a lifelong pursuit but the emphasis has always been on formal schooling which involves different degrees of immersion. Primary schools establish literacy and numeracy, secondary schools provide enabling sciences (mathematics, chemistry and physics), and tertiary schools stream specific scientific disciplines. However, some countries have opted for liberal arts and science programs at tertiary level and have moved scientific disciplines into quaternary education (professional degrees, research degrees, continuing education). In a recent curriculum review by Harvard College, they noted the enduring value of a liberal education in arts and sciences and their mission statement is to graduate broadly educated individuals, while encouraging them to develop greater understanding of one or another discipline (not to achieve mastery but to focus thinking). In Australia, there appear to be four major steams of undergraduate students in science faculties: those seeking a specified education prerequisite to employment; those complying with recommended courses for postgraduate entry into professional degrees; those seeking entry into research careers; and those seeking a broad general education. Clearly, one single program cannot cater for all their different needs and expectations. There are many coherent arguments for tailored teaching for different student cohorts; content can be modified and anecdotes can be varied for contextual relevance while teaching and learning processes can model workplace practices, attitudes and behaviours.

However, students vary considerably in their backgrounds. It is enigmatic that many university students enrolling in science have not formally studied biology. For them to understand the 'cutting-edge' of science requires strong foundations; students need to begin with basic concepts and fundamental knowledge. One solution adopted at my university has been to create a biology smorgasbord: i.e. to offer broad interdisciplinary courses to first year students so that they can sample everything. This strategy has four advantages: it gives students a holistic conception of biology; it establishes a level playing field; it provides them with sufficient information to make informed choices; and it defers their need to choose a more specified field of interest until later in their degree. The BSc is a flexible generalist degree which accommodates many fields of study. Students graduate with named 'majors' and many universities have progressed to named degrees to confer market advantage. Students tailor their programs and, indeed, increasing numbers seek double majors or dual degrees to improve employment opportunities. Science has been paired with law, business, economics, arts, education and engineering. Not all disciplines are accessible through an ordinary degree, so students must consider postgraduate options. There is a global trend to postgraduate entry in some professions (particularly medicine and veterinary science).

So how do science programs cater for such diverse clients? Should they be driven by provider supply or market demand? Ideally, these two parameters should be closely correlated but there are many examples of discordance. For example, hundreds of students graduate with degrees in biomedical science but only 10-15% get into postgraduate medical courses and only 5-10% take up biomedical research. What then do the remainder do with their degrees? The token answer is that they exited university with a generalist degree and became informed citizens with lifelong learning skills. The corollary is that the generalist degree could have had a focus other than biomedical science more appropriate for the final placement of these students. There is, indeed, a growing demand by students for counselling and advisory services so that informed career choices can be made (in some countries, this has spawned the novel industry of university brokering). The recognition and pursuit of different career paths reinforces the need for tailored programs and student streaming. The issue is now at what stage must students choose a stream (junior or senior level) or do they even get a choice? Several advanced learning schemes have been introduced which selectively target bright students but similar opportunities are not available for the masses. Should we afford equitable access for all or divide students into streams on the basis of their aptitudes, abilities or desires? This depends on whether we are in the business of mass education or vocational training. Universities profess to do both so we need to cater for our clientele.

RECOMMENDATIONS

Ultimately, reform in science education will revolve around money. In a period of unprecedented scientific and technological growth and socio-economic advancement that has generated more students, we need more money to train more staff to teach more groups with more quality. This will involve significant financial and cultural changes in the work-place as well as in the work-force.

It is proposed that Science Faculties in Universities develop consultative mechanisms to:

- establish basic standards in science curricula confluent with secondary school programs;
- identify and encourage institutional specialization to facilitate student streaming;
- formally adopt tertiary teacher training programs leading to postgraduate qualifications;
- remodel courses and classrooms to foster socially interactive learning;
- provide contextual, practical and discovery-based learning experiences for students; and
- integrate teaching and research activities at all academic levels.