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The Important Aspects of Learning and Teaching in Experimental Sciences

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ABSTRACT

The teaching and learning of experimental sciences, which primarily include the physical sciences, chemical sciences and the broad spectrum of biological sciences. Teaching and learning in the experimental sciences have to take account of a number of issues. By 2020, experimental science subjects are increasingly seen as difficult and unfashionable alongside the of new disciplines. Accordingly, the rise in student numbers has not been matched by a proportionate rise of numbers within experimental science disciplines and the proportion of students studying the basic science UG and PG courses is decreasing. This has serious implications for curriculum design, for approaches to learning and teaching and for systems, for student support and retention. The changing science from a level of curriculum and the move towards the examination. There are also QAA Subject Benchmarking statements (Quality Assurance Agency), and institutions are increasingly introducing module 'norms' for hours of lectures, laboratory classes, and tutorials, and may also define the extent and type of assessments. The Cell for Excellence in Teaching and Learning (CETLs) help the students in writing the practical report or structure or essay. The 'Differentiated learning' is, an emerging issue and may be taken as the intention to differentiate learning opportunities and outcomes, differentiation by ability, focus on the most able. This is a newly emerging issue in higher education.

Keywords: *Teaching, Learning, Experimental Sciences, Higher education.*

1. INTRODUCTION

Curriculum Development and Delivery

In common with engineering disciplines, within the experimental sciences the curricula, and even learning and teaching methods, may be partially determined by professional bodies and employers. With some professional bodies, recognition or accreditation of undergraduate programmes may simply indicate a focus on the scientific discipline involved without making any judgment about content or standards. Other professional bodies may provide indicative or core curricula as guidance with no requirement that such guidance is followed, though providers may find such guidance helpful in maintaining the content of their programmes against institutional pressures. However, professional bodies in the experimental sciences differ from engineering, where they are more definitive; their accreditation may be vital for future professional practice and may determine entry standards, detail curricula and assessment methods and minimum requirements for practical work.

There are also QAA Subject Benchmarking statements and institutions are increasingly introducing module 'norms' for hours of lectures, laboratory classes, and tutorials, and may also define the extent and type of assessments. Determination of the 'what and how' of teaching is no longer under the complete control of the individual teacher. Furthermore, discipline knowledge is expanding and undergraduate curriculum overload is a real issue in all the experimental sciences. Disciplines are becoming less well demarcated and significant knowledge of peripheral disciplines is now required if the integrated nature of science is to be understood.

The Role of Faculty

The involvement of employers in the design and delivery of courses and the development of work-based learning illustrate how outside influences affect courses. In part, the impetus has been to improve student employability as many organizations look to Higher Education to produce graduates with the range of skills which will enable them to make an immediate impact at work.

Recruitment Imperatives

A major challenge for the experimental sciences in India is undergraduate recruitment. Experimental science subjects are increasingly seen as 'difficult' and unfashionable alongside the plethora of new disciplines. Accordingly, the rise in student numbers during the past two decades has not been matched by a proportionate rise of numbers within experimental science disciplines and the proportion of students studying science courses is decreasing. The need for universities to fill available places inevitably means that entry grades are falling and students are less well prepared. This has serious implications for curriculum design, for approaches to learning and teaching, and for systems for student support and retention. How the changing science a level curriculum and the move towards the baccalaureate examination will affect this issue remains to be seen.

Enhanced Degrees

During the 1990s, science disciplines in India developed the 'enhanced' undergraduate degree. These grew from a need for more time at the undergraduate level to produce scientists and engineers who can compete on the international stage. Many programmes remain similar to the B.Sc./B.Eng/B.Tech. With a substantial project and some professional skills development in the final year. Others use a '2-plus-2' approach, with a common first and second year for all students and distinctive routes for year 3 of the B.Sc. and years 4 and 5 at Masters level integrated courses. In the latter case, there are issues related to the distinctiveness of the Bachelors and Masters routes

Participation in Learning

The percentage of the 18–24 age group participating in university education has grown. This increase has been accompanied by a diversification in student aspiration, motivation, and ability. The increased focus on the development of generic (transferable) skills has increased the employability of students in areas outside science (as well as within science) and less than 50 per cent of graduates may now take employment in the area of their primary discipline. The decline in the mathematical ability of young people is well researched and documented. The useful ideas and resources on mathematics support for students may be obtained from the India Higher Education Academy Subject Centres and Centres for Excellence in Teaching and Learning (CETLs). The ability to write clear and correct English has also diminished and students often do not know how to present a practical report or structure an essay.

The very able students often receive no additional provision though they should have equal entitlement to be developed to their full potential. 'Differentiated learning' is, therefore, an emerging issue and may be taken as, the intention to differentiate learning opportunities and outcomes, differentiation by ability, focus on the most able. This is a newly emerging issue in higher education and as yet there has been no full exploration of its implications or how it could be achieved.

2. LEARNING AND TEACHING

The learning and teaching methods are particularly important for the experimental sciences which are often heavily content driven. They are the lecture, small group teaching, problem-based learning, industrial work experience and practical work.

The Lecture

The lecture is still the most widely used way of delivering 'content' in experimental sciences, in which curricula are predominantly linear and progressive in nature with basic concepts that have to be mastered before the further study can be considered. In recent years many lecturers have introduced more opportunities for student interaction and participation, and use lectures to generate enthusiasm, interest, and involvement with the subject. The traditional lecture is essentially a one-way transmission of information to students, especially in large classes (over 100 students). The challenge is to make the lecture more akin to a two-way conversation. One solution is to promote interactive engagement through technology, via handheld, remote devices and use of ICT, with Microsoft PowerPoint that enables questions to be embedded within a slideshow. It needs the entire display screen to project a response grid which enables the students to identify that their vote has been received. Display of the question on which the students are voting, which must be clearly visible during thinking time, necessitates the use of a second screen, overhead projector or board. The logistics of providing the students with handsets must be considered. We issue handsets at the beginning of the course and collect them at the end, which avoids time lost through frequent distribution and collection of handsets.

The use of multiple-choice questions (MCQs) as interactive engagement exercises within our lectures. The electronic system has provided us with valuable insight into what makes a 'good question', i.e. one where a spread of answers might be expected or where it is known that common misconceptions lurk. This method is employed with the interactive question episodes throughout our first-year chemistry and physics variety of ways: To simply break up the lecture, to regain audience focus and attention and as a mild diversion timed around halfway through.

Interrogating Practice

To serve as a refresher or test of understanding of key points from material previously covered. As a vehicle for peer instruction, capitalizing on the social context of the discussion and peer interaction. The process for one of these episodes is that a question is posed and voted on individually. Following display of the class responses, students are invited to talk to neighbors and defend or promote their own viewpoint and why they think it is correct. The class is then repolled and the revised response distribution is displayed. In 'contingent teaching' the interactive engagement episodes act as branch points in the lecture. Subsequent progression is contingent on the response from the students. A question which, for example, 80 per cent of the students gets wrong would indicate either a fundamental misunderstanding associated with the material, or a lack of clarity in the exposition of it, or both. Some corrective action is clearly necessary and, in this respect, the lecture truly becomes a two-way experience. It is important not to rush through these episodes, but to give adequate thinking time. A cycle of peer instruction can take 10 to 15 minutes, perhaps longer if preceded by an orientation to the topic. One the most difficult things to evaluate after using this methodology is the effect it has on student learning. In physics and chemistry course the handsets and their use often rated as one of the best things about the course. The questions make you actually think about what the lecturer has just said.

Small Group Teaching

The traditional small group tutorial is increasingly under pressure as group sizes grow. It may be difficult to form of teaching for new staff. Small group teaching can be particularly challenging in sciences where the discipline itself does not always present obvious points for discussion and students often think there is a single correct answer. If problem-solving is an aspect of small group work, then it is worth designing. This provides opportunities for students to discuss multiple responses rather than simply work out where they 'went wrong', but this is not always easy to accomplish.

Problem-Based Learning

Problem-based learning (PBL) is now being adopted in other 'professional' disciplines. It is a style of learning in which the problems act as the driving force for student-directed learning. All learning of new knowledge is done within the context of the problems. PBL differs from 'problem-solving' in that in PBL the problems are encountered before all the relevant knowledge has been acquired and solving problems results in the acquisition of knowledge and problem-solving skills. In problem-solving, the knowledge acquisition has usually already taken place. It is claimed that a PBL approach: produces better-motivated students, develops a deeper understanding of the subject, encourages independent and collaborative learning, develops higher-order cognitive skills, develops a range of skills including problem-solving, a group working, critical analysis and communication.

In PBL the curriculum is organized around the problems which must be matched to the desired learning outcomes. Students work in groups to solve the problems. There are no lectures, instead, students engage in self-directed learning and the tutor acts as a facilitator, mentor or guide ensure inclusive group working. Many institutions may be short of the sort of learning spaces that helps PBL to work well - flat seminar rooms with movable furniture. Problems that are used for PBL should address curriculum objectives, be real and engaging, be 'fuzzy' and place the group in a professional role, i.e. as physicists or chemists. It is not a trivial task to develop effective 'problems' for PBL, but many academics think the initial investment is worth the effort.

Industrial Work Experience

Industrial placements, varying from a few months to a full year, are increasingly a feature of experimental science programmes. Employers value work experience and students who return from industrial placements are generally highly motivated and have developed a range of transferable and personal skills and appropriate attitudes. Many academic departments have identified members of staff who are responsible for building partnerships with employers, placing students and supporting them during their work placement. The aims of the work experience have to be clear to all three parties. If the placement is credit-bearing, there have to be outcomes that can be assessed. Ensuring consistency among multiple assessors in multiple workplaces is difficult, as is ensuring that all students' projects are of equal difficulty and that help is provided in the workplace on an equal basis also defined good practice and expected standards. The students with industrial experience will get good practical knowledge about work.

Finding the Placement

Students may be required to find and apply for their own placement (a useful learning experience) or they may be fully supported through a departmental system which finds placements for them and thereby provides the best service to students.

The Partnership: The Company, the University, the Student

A successful partnership will have defined statements of responsibilities, expected to learn outcomes and behaviors. These should be set out in a handbook, sectionalised for students, visiting tutor and industrial supervisor.

Preparing the Student

Students need to be informed (optimally by presentations from industrialists or students returning from placement) of the benefits of work placements, the time-scale and methods of application and the normal requirements of the workplace (such as dress code). Courses on writing CVs, application forms and interview techniques are important.

Maintaining Contact with the Student

Students should be encouraged to contact the university to discuss problems and successes, are best supported by a visit by academic staff and will benefit from electronic support, either between staff and students or between peer groups of students.

Assessment

Students need to be conscious of their development and should assess their own progress via a portfolio, personal development log or another form of personal development planning. Essays or project reports may also form a major part of the assessment process.

Practical Work

Laboratory/practical classes and workshops play a major role in the education of experimental scientists. In this environment, students learn to be scientists and develop professional skills and attitudes. Sciences are practical subjects and academics see this practical experience as vital and non-negotiable. Such learning experiences are very expensive in terms of staff time, support staff, consumable materials and equipment, and are vital for the development of practical, discipline-specific skills, as well as providing rich opportunities for the development of intellectual and transferable skills. Although students are carrying out an investigation or producing a design, the learning objectives for practical sessions are usually much broader and might include the following. To gain practical skills, gain experience of particular techniques or pieces of equipment, produce a design, plan an experiment, make links between theory and practice, gather, manipulate and interpret data, make observations, form and test hypotheses; use judgement, develop problem-solving skills, communicate data and concepts, develop personal skills, develop ICT skills, develop safe working practices, motivate and enthuse students, simulate professional practice.

Practical work may take very many forms. It may be very constrained, where students follow detailed instructions with little scope for independent thinking. These experiences have their place in developing basic practical skills and giving students confidence. Practical work may take a more open-ended approach, developing practical and technical skills, as well as design skills, problem-solving and application of theory to practice. Assessment is an issue since it is often the ability to write up laboratory exercises that are assessed rather than the acquisition of practical skills and appropriate attitudes.

Graduates have made it clear that they are generally well prepared for the practical issues they have to address in their early employment possibly because of reduced quantity and quality of practical work offered on courses. The final year project has also undergone a change. For example, literature reviews, computer-based modeling, desktop impact assessments and surveys of all sorts are now offered as alternatives to the laboratory-based project. Such alternative projects may better prepare students for the career to which they aspire. Fieldwork has been a strong feature of courses in many disciplines but has come under pressure in some institutions as it is expensive and time-consuming and may present health and safety challenges. Many graduates value their experience of fieldwork and any decision to reduce fieldwork availability or practical content should be taken carefully. The students should come to a laboratory, workshop or field trip already familiar with the activity they are about to perform and relevant background theory. Unless this requirement is made explicit, students will turn up not having read through their schedule or manual. The easiest way to ensure that students think about the practical before they arrive is to set a pre-practical exercise which may be fairly short and consist of a few questions, based on the manual or handout they will use. The students should be required to complete the exercise before starting the session. Such ‘pre-pracs’ or ‘pre-labs’ may be paper-based or automated, via the web or a VLE, or use a simulation.

Fieldwork plays a central role in most modern environmental science courses. It provides students with opportunities to develop their discipline-specific and transferable skills, including techniques/methods for sampling and data analysis, and invaluable training in problem-solving within ‘real life’ scenarios. There remains, however, a challenge in fieldwork with undergraduate students in the early stages of their degree courses. The reasons for this are not simply limited to the subject material that needs to be covered, which often demands some subject inter disciplinary. The *process* of fieldwork is unfamiliar to most students, and as a result, an appreciation of demands and expectations is often lacking. In order to address this issue, a number of methods can be useful, including introductory lectures and support documentation. Unfortunately, student feedback suggests that such methods are often inadequate at delivering the most valuable ‘message’ and there can be a risk of information overload. As an alternative, web-based materials offer the possibility of combining various elements of preparative fieldwork in a flexible and interactive format.

To better prepare, students developed an interactive website which is far from being a substitute for the hands-on nature of the fieldwork but focuses more on the preparative components that are required in order for the fieldwork to be effective. Along with suitable graphics and links between the different site visits, each section has an interactive self-assessment section that enables students to evaluate their own level of understanding, become more aware of their own learning and develop independence. The website is accessible at all times, and a scheduled session, approximately one week before the fieldwork, replaces introductory lectures.

The student feedback is also important. Another issue vital to an effective practical session is the quality of support from postgraduate students or postdoctoral workers used as demonstrators. In order to be effective, they have to be familiar with the activity, well briefed, have a good rapport with the students and be willing and able to deal with any problems. Most universities organize generically applicable training sessions for demonstrators, but lecturers involved in practical classes are well advised to hold a briefing session immediately before the activity to ensure demonstrators are familiar with the purpose of the class and with equipment and have sufficient background knowledge to deal with any queries. If demonstrators are involved in marking students’ work, then detailed marking schemes should be available to ensure consistent standards.

Ethics

The issue of ethics is increasingly prominent, as illustrated by some quotes. Expect staff to take into account ethical and sustainability issues when making decisions and choices. Project management must take ethical and environmental issues into account. The professional organizations also require ethical behaviors in their codes of conduct, and within the experimental sciences, the nature of the disciplines exposes a host of ethical issues. Graduates need to be able to recognize ethical issues and be acquainted with the aspects of constructing an argument based on ethical principles. (e.g. autonomy, beneficence, non-male efficiency, fairness and greatest good to largest number). Finding out the strategy for skills development in the institution and department. Listing of the transferable skills development opportunities available in the courses.

Students in the Faculty of Sciences participate in laboratory exercises or final-year projects in which they or their colleagues act as subjects. To address this lack of knowledge and to increase student awareness of the ethical issues involved. The seminar, which was co-taught with a colleague from the Interdisciplinary Ethics Applied Centre of Excellence in Teaching and Learning (IDEA CETL), the students were divided into small groups to discuss and debate what they understood by ‘informed consent’, their deliberations being fed into a subsequent plenary session. They were also provided with case studies in which, within their small groups, they had to discuss whether the subjects had given their ‘informed consent’.

The co-teaching of the seminar by a biological scientist and an ethicist enabled both the scientific and ethical issues surrounding the use of humans as subjects in research to be fully addressed. Feedback on the lecture and seminar was sought both from staff who were observing this new provision and from the students themselves, both groups finding them extremely educational and informative. As a result, in 2007 to 2008, other undergraduate and postgraduate degree programmes within the Faculty, in which students participate in practical work in which they or others act as subjects, will be provided with this training.

Assessment of Student Learning

Even with modules of equal credit rating, there are huge variations in the amount of staff time spent on assessing students, student time spent on being assessed, time spent on giving and receiving feedback. While some universities are attempting to standardize assessment across modules, variations must be expected since the assessment should be linked to the learning objectives and to the teaching methods. The unseen written examinations still remain the principal means of summative assessment within experimental sciences. For new academics, one of the most daunting tasks is to write their first examination questions, often before the course has been taught. Many academics consider unseen written examinations to be the only rigorous form of assessment, even though such assessments cannot measure the range of qualities and skills demanded of a professional scientist. One distinctive feature of experimental sciences is the assessment of large numbers of written laboratory or practical reports. The value of repeatedly assessing such exercises, which may not measure practical skills at all, is not always questioned, and alternative possibilities are reviewed elsewhere.

3. THE USE OF INFORMATION TECHNOLOGY

Apart from the generic use of ICT in word-processing, spreadsheets and so on, increasing use is being made of electronic resources to support learning and teaching in experimental sciences (e.g. molecular modeling and computer animation). This includes the use of software packages, managed or virtual learning environments or web-based resources. One of the common uses of software is for mathematics support where a software or web-based resource can be accessed as needed by the students. Simulations of experiments are another area where the use of ICT can be beneficial. Laboratory use of expensive equipment is not always available to all students and so a simulation can provide large numbers of students with some experience of a specialized technique, perhaps through distance learning. Simulations may enable students to generate a large number of results in a fraction of the time it would take to generate them in a laboratory and can allow students to use learn by discovery methods. Making mistakes in execution or design of experiments can be too costly or dangerous to be allowed in the laboratory but may be allowed on a simulation. Experimental design can also be taught using trial-and-error methods. The Higher Education Academy Subject Centres can provide details of simulations available in each discipline.

In an ideal world, the content of a university science practical course would be determined entirely by what is academically desirable. In reality, we are restricted by space limitations and to what is physically and financially achievable. The setting up of multiple sets of experiments is significant it would be most cost-effective if wide access to a single experimental rig could be offered. The web was not designed as a medium for running experiments, so practical difficulties remain. However, the advantages of the creation of a pool of experiments, widely accessible through the internet, are very substantial.

Support

Some of the most useful support can be obtained from colleagues in the same discipline and many professional bodies and learned societies have considerable teaching resources available from their websites. The Higher Education Academy Subject Centres provide discipline-specific support for all teachers in higher education. Their services are free and many also provide services specifically for new academics.

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