Towards conceptual understanding: bringing research findings into the lecture theatre in tertiary science teaching

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Abstract: *Science education has long cherished teaching and learning strategies which actively engage students and create meaningful understanding of abstract concepts. Due to the diverse ways in which science is practised, professional scientists and educators have the natural advantage of being able to use a range of teaching techniques which they assume will help motivate students. However, students' prior expectations, existing schema and conceptions about the topics being taught and their understanding of learning can help or hinder their conceptual development in all science disciplines. Everyone relies primarily on his/her senses of sight, sound and touch to perceive the world and therefore to learn. Although each person has differing abilities in each mode, the predominant learning style of individuals (e.g., whether visual, auditory or kinesthetic) and its impact on conceptual understanding is often overlooked in tertiary Science teaching. Incorporating the variability in individual learners may help educators determine which strategies assist and which limit an individual's understanding. Concomitantly, some changes in traditional lecturing practices may be beneficial in large first year university classes in order to improve the learning experience of many of our first-year science students. This is a preliminary study which reports on an investigation into the effectiveness of teaching and learning strategies, based on recent literature, which were developed to cater for individual differences in learning modalities in first-year classes at the University of Western Sydney. The aim of these strategies was to increase the conceptual understanding of abstract concepts such as photosynthesis. Student responses to an open-ended question regarding their overall learning experience indicated that a variety of teaching and learning strategies, which mix auditory, visual and kinesthetic learning modalities with class experience, have been effective in the development of conceptual understanding.*

Introduction

The aim of science education is to help students develop a deep understanding of abstract concepts. Although many teaching and learning strategies have been developed to facilitate this process, there are a wide range of factors that influence its ultimate success. Factors which have been shown to influence student learning are student motivation and understanding by the teacher of 'what the learner is doing', rather than 'what the teacher is doing' (Biggs 1999). These ideas follow from the earlier research of Piaget (1929) and Ausubel (1968) whose seminal studies indicated as children mature, particular stages of development occur that influence the way they can learn increasingly abstract concepts. It is also well recognised that students have existing schema or alternative conceptions (misconceptions) which can be personal in nature, highly resistant to change, may exist alongside new conceptions and sometimes be contradictory (Osborne and Freyberg 1985; Driver and Bell 1986; Fensham 1994; Wandersee, Mintzes and Novak 1994). Student beliefs about the nature of knowledge and learning have also been shown to affect their learning and academic performance (Schommer 1998). It has been known for some time (Perry 1968 as cited in Schommer 1988), that students pass through stages of development in their epistemological beliefs. In the early stages of tertiary education, many students see 'knowledge' as being either 'right' or 'wrong' and believe that authority figures know the answers. When students reach the later stages of development, they realise there are multiple possibilities of knowledge and personal interpretation (Schommer 1988, 1993).

The first step in human processing and learning is, however, perception (Johnstone 1997). Three of the five senses are used to perceive, store and retrieve reality; sight, sound and touch. Each person has differing abilities in each mode; based on the sense preferred people can be classified broadly as visual, auditory or kinesthetic learners. Generally, a person communicates best with someone of the same modality (Grinder 1988). Within any group of learners, there will be students with different preferred learning modalities. Although many tertiary science educators are aware of the differences in learning modalities of their students and the need to address both the breadth and depth of their teaching and learning approaches so that they cater for all, there is sometimes an inherent 'energy barrier' to translating the results of educational research into real changes in lecture-room practices (Gilbert, De Jong, Justi, Treagust and Van Driel 2002). Traditionally, transmissive, teacher-centric models are the most common teaching model in our tertiary institutions (Fuller 1998; Beaver 1999; Dearn 1999). As well as being often a passive mode of delivery, the emphasis of this didactic style caters for only a small percentage of learners in the audience, mainly those who are auditory learners; although some styles of presentations may also cater for visual learners. Less often is a multisensory approach used (Whitefield 1996); one which incorporates all the modalities of learning. Current research also suggests that because many concepts needed to understand scientific phenomena are counter-intuitive and abstract, the incorporation of a range of different learning modalities may help students develop deeper understanding.

The aim of this paper is to describe teaching and learning strategies which are inclusive of the differences in the learning styles and modalities of students, i.e. auditory, visual and kinesthetic as described in the current pedagogical literature, and which have been specifically developed for large classes (up to 470 students). The hypothesis tested was that teaching and learning strategies which use a range of learning modalities will increase the understanding of abstract and counter-intuitive concepts in science, specifically those of the submicroscopic aspects of photosynthesis. The evidence presented is students own comments on how these strategies have helped their understanding of these concepts, and these preliminary results will inform the future design and development of these programs.

The Teaching and Learning Strategy

Students find the submicroscopic concepts involved in photosynthesis and cell metabolism (respiration) notoriously difficult to understand (Wandersee et al. 1994). Many of them have similar problems understanding molecular concepts in their chemistry units and many have little High School chemistry background. We have developed a sequence which incorporates a range of teaching styles designed to incorporate diverse learning modalities. The sequence commenced with a traditional didactic lecture, mostly auditory based, but incorporating visual stimuli, such as diagrams and animations using *PowerPoint*. Following this, students made a three-dimensional model of a chloroplast using everyday items including paper plates, sponges, crepe paper and plastic bags, in small-groups facilitated by demonstrators. More complex development of the model, including 'animations' to show chemiosmosis using paper H^+ ions and reactions of the cytochrome chain, was created using coloured beads and different coloured thumbtacks to represent various enzymes and ATP synthase.

After this initial lecture and practical, the concepts of photosynthesis were re-taught within the lecture series – but this time emphasising kinesthetic and visual modalities. The kinesthetic teaching strategy was a role-play. The lecture theatre was set up as part of the cell, with Photosystyem I and Photosystem II (protein complexes within the membrane of a chloroplast) clearly identified and the students were involved as various ions, electrons and molecules identified by A4 paper labels. The overhead projector was used to act as photons of light. In the darkened lecture theatre, the photosynthesis reaction was started when the light from the overhead was shone on 'Photosystem II'. A student was asked to come and eject an 'electron' from 'Photosytem II' and take it to an 'electron acceptor' which existed at the back door of the lecture theatre. Other students in the audience were asked to visualise an electron in their cupped hands and eject it, by throwing away the imaginary electron. Another student was then asked to replace the 'missing electron' by taking an electron from 'water', which is depicted on the board as $4H^+$ ions plus 4 electrons plus 2 oxygen molecules. In this process, the lecturer shows how an H^+ ion' is released. The overhead projector was turned off and turned back on again, and the whole sequence repeated 3 times (representing 4 photons of light in total and ejecting 4 electrons). At this point, it was explained that the 2 oxygen atoms can combine to form an O_2 molecule, and a student physically combined these and carried a symbol for O_2 out through the door, representing diffusion of the oxygen gas out of the cell. Since this was a tiered lecture theatre, the released electrons were passed from hand to hand down the 'electron transport chain', (the steps, represented by other students) to replace the 'electrons' ejected when a 'photon' (the OHP) was shone on 'Photosystem I'. This was repeated again 4 times until the electrons were finally passed to $NADP^+$ to form NADPH + H^+ (cofactors within the biochemical pathways). It is important throughout this sequence to use as many students in the lecture theatre as possible and finish with H^+ diffusing through ATP synthase (the final, membrane-bound, enzyme in the photosystem pathways). It was also possible to simulate the physical arrangement of how electrons are transported in enzyme-mediated reactions within a membrane..

To consolidate the visual aspects of learning, this role-play was combined with an increasingly complex summary of events being simultaneously constructed on an overhead (or *PowerPoint* or the white-board) as the sequence progressed. During all these sessions students were requested to make their own in pictorial image of what was occurring. To facilitate discussion of any misconceptions, and to revise these complex teaching strategies, students were asked to diagrammatically depict what is occurring in a chloroplast in subsequent small-group situations (in this case a tutorial session). This was followed up by advising students to revise their understanding with use of the textbook, and interactive CDs on photosynthesis.

The evaluation process

As this was a preliminary study of the practical effects of bringing some of the research findings into a large lecture situation, student responses to an open-ended question included within the standard student evaluation (Student Evaluation of Educational Quality, UWS Educational Development Centre) were used to evaluate how students rated the success of incorporating different modalities and their effect on conceptual understanding. The open-ended question asked them to 'please indicate the important characteristics of this lecturer/class that have been most valuable to your overall learning experience'. There were 203 surveys returned; 187 of which contained comments in the section with the open-ended question. Responses were grouped into the following categories; identified that the use of different learning modalities increased conceptual understanding; linked teaching/learning techniques with increased conceptual understanding; noted that the inclusion of students and interactive teaching strategies increased conceptual understanding; and stated that some aspect of the teaching approach was positive. The percentage of responses were then tallied (see Table 1).

Results

Overall, students viewed the teaching and learning methodologies in this unit as positive (Table 1). Although, this was an open-ended question some students identified that different learning modalities were used, especially kinesthetic strategies (which were described by some students as 'kinetic' or 'physical'). This was surprising given that students had not been told explicitly that these teaching and learning methodologies were being used, nor were they identified with technical pedagogical terms. Over half the students commented (57%) that the strategies used within the unit increased their conceptual understanding. The remainder (almost 43%), who did not identify specific strategies or outcomes, nevertheless commented positively (Table 1). As there was no scaffolding within this question, it is possible that some of these students did not feel it necessary, or did not have the vocabulary, to make explicit comments on particular aspects of the teaching/learning strategies. It should be noted that, although (16) students returned evaluations with no comments in the open-ended section which have not been included in the tally of the percentage included in each category, there were NO negative responses to this question. Comments on a companion question, which asked students to comment on ways in which the unit could be improved were universally constructive and 'sensible', with no frivolous or completely negative comments. On the contrary, many students made comments that there was nothing that the lecturer could do to improve the teaching strategies used within the unit, and some took the opportunity to make more personal positive comments on the teaching/learning strategies.

Table 1. Classification of students' responses into categories describing teaching effectiveness in first year Biology, University of Western Sydney, 2004

Category of student response	No. of student responses to open-ended question	Percentage of student responses to open-ended question
Identified that the use of different learning modalities increased conceptual understanding	45	24.1
Linked teaching/learning techniques with increased conceptual understanding	37	19.8
Noted that inclusion of students and interactive teaching strategies increased conceptual understanding	25	13.4
Stated that some aspect of the teaching approach was positive	80	42.7
No response to open-ended question (not included in % calculation)	(16)	-
Total	**203**	**100**

Discussion

From our experiences described here, we believe that using teaching and learning methodologies which are inclusive of learning modalities increased student understanding of abstract concepts without hindering other effective learning strategies. This may be partly because we constructed links from known everyday 'concrete' items (including themselves) to abstract concepts such as photosynthesis, thus helping the 'unknown' to become more 'real' (Oakley 1994). Other similar teaching sequences, which have focused on teaching cells, cell metabolism (including a complicated role play), genetics and protein synthesis within cells, have also been developed. Although we have used the example of photosynthesis in this paper, the evaluation is based on the entire range of teaching and learning activities used during the semester. Indeed, the role-play on photosynthesis described in this paper was developed because students requested it, when they reflected on previous kinesthetic teaching strategies that had helped them understand difficult concepts. Further, we also believe that the process of being inclusive of different learning modalities breaks down barriers to learning and understanding. These barriers include those between other people in the room (other students and tutors) and the barriers which exist between themselves (the learners) and the textbook. The structure and content of textbooks may become clearer when students can relate the written materials to concepts taught using everyday examples and materials.

The first step in developing teaching and learning strategies in different modalities, however, is to think about the lecturing style which we use and feel most comfortable with. We should all become aware of our own preferred learning modality (Bogod 1998). Auditory and visual modalities appeared to be the preferred by traditional science educators, rather than kinesthetic. Perhaps this is because it takes more time to think about teaching strategies which can be used in this area, or perhaps these techniques are seen to be comfortingly 'right brain' or 'touchy feely' or 'arty' by other scientists. However, we need to remember that scientific research requires vision, imagination and activity – which are combinations of our 'artistic' and 'logical' facilities (Mitchell 2004). It is fun to incorporate these skills that we possess as scientists into our teaching programs.

How can we incorporate more kinesthetic teaching strategies in a simple way? Do you ever at times put your hands out wide and say ‘the thing was this big’? To teach using kinesthetic we need to encourage the students to use their hands. At UWS we have also used successfully a number of visualisations during which the students need to close their eyes and imagine the process in their mind, such as when they were one cell, or the moment of fertilisation, or in chemistry what the nucleus of an atom would ‘see’ if it looked out towards ‘its’ electron cloud. You will be able to think of many activities which can be used to be inclusive of the different learning modalities of your students, depending on your own experiences and imagination. Such inclusiveness in learning modalities does not mean dispensing with the didactic lecture, but it does mean modifying what is done within it. Similarly, laboratory sessions, the other main integral teaching and learning vehicle for the delivery of content (Hodson 1988, 1990), can be used to support as opposed to not contributing to conceptual understanding (Hodson 1998).

Abstract and submicroscopic concepts are difficult to relate to students. Teaching strategies that use a wide range of learning modalities are more inclusive and provide opportunities to actively engage students with the content. The results of this evaluation were sufficiently encouraging to inform the design of future qualitative and quantitative studies into the effects of these teaching/learning strategies. We believe through this process we may facilitate the conceptual conflict necessary before students can reconsolidate their learning and prevent many students ‘marking time’ in their development of deep understanding.

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