



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

Pauline M. Ross and Deidre Tronson, College of Science and Technology,
University of Western Sydney
pm.ross@uws.edu.au d.tronson@uws.edu.au

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 Photosystem 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 ‘Photosystem 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 $\text{NADPH} + \text{H}^+$ (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 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
<i>Noted that</i> inclusion of students and interactive teaching strategies increased conceptual understanding	25	13.4
<i>Stated that some aspect of the</i> 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 comfortably '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.

References

- Ausubel, D.P. (1968) *Educational psychology: A cognitive view*. New York: Holt, Reinhart and Winston.
- Beaver, J. (1999) Musings on motivating modern students. *Higher Education Research and Development Society of Australasia News*, August.
- Biggs, J. (1999) *Teaching for quality learning at University – what the student does*. Buckingham, UK: SRHE and OUP.
- Bogod, L. (1998) Learning modality [Online] Available: http://www.ldpride.net/learning_style.html [2004, August 30].
- Dearn, J. (1999) Dull to learn, dull to teach: engaging with science through discussion and collaboration. *Chemistry in Australia*, **April**, 21-28.
- Driver, R. and Bell, B. (1986) Students’ thinking and the learning of science: a constructivist view. *The School Science Review*, **67**(240), 443-456.
- Fensham, P. (1994) *The content of science: a constructivist approach to its teaching and learning*. London: Falmer Press.
- Fuller, R. (1998) Encouraging active learning at university. *Higher Education Research and Development Society of Australasia*, **20**(3).
- Gilbert, J.K., De Jong, O., Justi, R., Treagust, D.F. and Van Driel, J. (2002) Research and Development for the future of Chemical Education. In J.K. Gilbert, O. De Jong, R. Justi, D.F. Treagust, J. Van Driel. (Eds) *Chemical Education: Towards Research Based Practices*. Kluwer Academic Publishers, The Netherlands, 391-408.
- Grinder, M.A. (1988) *A Workshop in Neurolinguistic Programming Excellence in Teaching Seminars* L. Smith, B. Verey, Nyar, J.
- Hodson, D. (1988) Experiments in science and science teaching, *Educational Philosophy and Theory*, **20**(2), 53-66.
- Hodson, D. (1998) *Teaching and learning Science: towards a personalised approach*. Buckingham, Philadelphia: Open University Press.
- Hodson, D. (1990) A critical look at practical work in school science. *School Science Review*, **70**, 33-40.
- Johnstone, A.H. (1997) ‘.....And some fell on good ground’ *University Chemistry Education*, **8**, 11-13.
- Mitchell, N. (2004) Left Brain, Right Brain [Online] Available: <http://www.abc.net.au/science/features/brain/default.htm> [2004, August 30].
- Oakley, C.R. (1994) Using socks and chromosomes to illustrate nuclear division, *The American Biology Teacher*, **56**(4), 238-239.
- Osborne, R. and Freyberg, P. (1985) *Learning in Science: The implications of children’s science*. Heinemann publishers, New Zealand.
- Piaget, J. (1929) *The child’s conception of the world*, London, UK: L Routledge and Kegan Paul.
- Schommer, Z.M. (1988) Effects of beliefs about the nature of knowledge on comprehension. *Journal of Education Psychology*, **82**(3), 498-504.
- Schommer, Z.M. (1993) Comparison of beliefs about the nature of knowledge and learning among postsecondary students. *Research in Higher Education*, **34**(3), 355-370.
- The Lab (2004) [Online] Available: <http://www.abc.net.au/science/features/brain/default.htm> [2004, July 9].
- Wandersee, J. H., Mintzes, J.J. and Novak, J.D. (1994) Research on Alternative Conceptions in Science. In G.L. Gabel (Ed) *Handbook of Research on Science Teaching and Learning: A Project of the National Science Teachers Association*. Macmillan Publishing Company New York, 177-210.



Whitefield, D. (1996) Look, listen, touch and experience – it makes sense to me! In J. Abbott, L. Willcoxson (Eds) *Teaching and Learning Within and Across Disciplines*. Proceedings of the 5th Annual Teaching and Learning Forum Murdoch University Perth, 161-164. [Online] Available: <http://lsn.curtin.edu.au/tlf/tlf1996/whitefield.html> [2004, July 2004].

© 2004 Pauline M. Ross and Deidre Tronson.

The authors assign to UniServe Science and educational non-profit institutions a non-exclusive licence to use this document for personal use and in the courses of instruction provided that the article is used in full and this copyright statement is reproduced. The authors also grant a non-exclusive licence to UniServe Science to publish this document in full on the Web (prime sites and mirrors) and in printed form within the UniServe Science 2004 Conference proceedings. Any other usage is prohibited without the express permission of the authors.



Developing the courage to be incompetent

Carol J. Steiner, Faculty of Informatics and Communication
Central Queensland University
c.steiner@cqu.edu.au

The Australian Government's innovation statement, *Backing Australia's Ability* (DEST 2001) committed them to creating 21,000 university places over five years in science, technology and mathematics courses that will 'meet the needs of industry.' But little research exists on how to prepare science students for industry work. One of many critical reviews of undergraduate science education in America (National Research Council, 1995, p. 4) reported:

The needs of the workforce are changing. This dynamism of the labour market is putting a premium on students who have a broad knowledge of different subjects, skill in synthesising and communicating information and the ability to work in teams. Students educated with a narrow disciplinary focus and with solitary learning styles can have difficulties in adjusting to such an environment. Indeed, such difficulties are a dominant theme in the complaints made by business leaders about contemporary undergraduate education.

This paper reports what one successful innovation consultancy thinks makes scientists valuable to industry. It is the product of a 3-year qualitative study of commercial innovation and innovators (Steiner 1996). The consultancy studied employs 90+ physicists, chemists, computer scientists, engineers and industrial designers. After presentation of its empirical data, this paper explores philosophically why it is difficult to produce innovators like this through conventional science education. It suggests it is difficult to produce many of the characteristics of innovating scientists because they are the characteristics of scientific incompetence. It further suggests it takes courage to be incompetent and it concludes with some preliminary suggestions for how science educators can tap into the student places created to support industry by helping science students find the courage to be incompetent.

Definitions

Competence: Kuhn (1970) suggests members of a scientific discipline community are judged as competent by their fellow members on the basis of their adherence to and skilled employment of a disciplinary matrix or paradigm—that is, the beliefs, practices, values and world view of their discipline. Heidegger (1977) says their acceptance by the community is conditional on them not questioning or challenging their paradigm beyond what is necessary to maintain its validity. Scientists need for professional acceptance affects their identity, their sense of themselves as 'good' scientists (Heidegger 1996). On my interpretation of Kuhn and Heidegger, I define 'competence' as the practical and philosophical acceptance of one's paradigm and identity without challenge and without questioning.

Incompetence: If we accept my philosophical definition of competence, then it follows that to be *incompetent* does not mean merely to be unskilled or careless. Rather, to be incompetent is to be willing to question and doubt one's paradigm and to work outside it sometimes. Drawing on Heidegger (1996), I say to be incompetent (authentic) as a scientist means to see oneself as a unique and free individual rather than as a discipline-defined (inauthentic) identity who conforms to a paradigm. This paper suggests that incompetence defined like this is what makes innovation possible and is the basis for the characteristics the innovation consultancy prefers.



Innovation: Mogee (1993; p. 412) defines innovation as ‘the process by which technological ideas are generated, developed and transformed into new business products, processes and services *that are used to make a profit and establish marketplace advantage*’ (my emphasis). Innovation is not about ideas but about realised, operationalised ideas that actually make money rather than only having money-making potential. This distinction was clearly articulated in the recent Government review of Cooperative Research Centres (Howard 2003).

Innovation as Mogee defines it calls for certain skills and attitudes that the management team of the innovation consultancy describe in the next sections. These are the characteristics they look for (and have found) in scientists and engineers they hire for their consultancy. These characteristics resonate throughout seminal innovation studies (Schon 1963; Robertson, Achilladelis and Jervis 1972; Makino 1987; Kanter 1988; Nonaka 1990; DeNovellis 1992; Hinterhuber and Popp 1993). The managers’ remarks emerged in lengthy individual depth interviews (two to six hours) with all ten directors and business group managers. They were interpreted hermeneutically from a Heideggerian phenomenological perspective which is synthetic rather than analytic, that is, it looks for relations rather than distinctions. It is not a ‘scientific’ methodology but an interpretive one in which impressions are as significant as ‘facts.’

Findings

Skills and Qualities of Innovators

According to the managers, innovators must be energetic, enthusiastic, competitive, innovative, thrive on change, diversity and challenge, and be able to live with uncertainty. They must be intelligent and able to respond to surprises in client situations. They must also be self-starters and high achievers. They must be ‘sparkly’ people. They must not be reticent; they should be confident. One said they should have the highest ambitions to achieve and another said they needed drive and the ability to make things happen. ‘There are plenty of technical people or creative people out there, but they don’t have the confidence or drive to make things happen.’ Another said, ‘They need a lot of drive that comes from their personality rather than from management.’ A director prescribed, ‘People who are team players but self-directed.’ A business unit manager said, ‘They should have wide vision of the work that they do and of themselves and a wide range of interests rather than tunnel vision.’ He continued:

Because no one person can know much about a range of disciplines—electronics and market research for example—they need to be able to talk to each other about the consequences of some thought or idea or new suggestion. They need to be able to accept new ideas and think about what the implications are for their specific component of whatever it is they’re doing and they need to be able to say whether it’s good, bad or indifferent or leads to new possibilities or it closes off some possibilities. People need to have an open mind about what they’re doing and be prepared to accept other people’s ideas and use them in their own area of skills or qualifications.

A director identified a complementary skill:

The place needs people who communicate well so they can assert a lateral idea because someone’ll always say, ‘No, it won’t work’. You need to have communication skills and the confidence in a team environment to assert a different approach that might be the most innovative, but you have to drag the troops with you. How creative the organisation is is about balancing the need to get consensus from the team to move forward quickly with individuals expressing alternative views.

Social skills include being personally agreeable and having people skills. Managers say innovators must get along with other people on the team, with clients and with clients’ staff who may feel threatened by the consultancy’s involvement. They should be able to communicate well both in written and oral form. They also should be good listeners and empathetic with clients whom the



director who listed this quality seems to equate with being able to predict what clients expect or how they will react. But managers are not only looking for a range of skills and qualities. They are also interested in how potential innovators understand themselves, their work and their obligations in the workplace. This information emerged in response to the question: What attitudes should an innovator have?

Attitudes of Innovators

Some of the recurring themes in response to this question were teamwork, problem-solving and desire to learn. A business unit manager pointed out that there was no room for individualists, prima donnas and stars. He said, 'They will be team players, not an ego kind of person who wants to go out and do it all themselves. It takes a certain maturity to realise that when you're working for a client, it's not your design that's going to save the day. It's a real team effort.'

Commenting on the problem-solving nature of an innovator's work, a director said he looks for 'a challenge-seeking attitude.' He explained, 'They have to respond positively to things going on outside rather than curling up in their shells and waiting for it to go away.' Two directors also mentioned the importance of wanting to learn new things. One said, 'They must want to learn and not imagine that they know everything, but at the same time they have to have considerable confidence in their abilities.' Another said innovators must be 'interested in their discipline, interested in commercial factors and not just content to play transistors in the back room.' A business unit manager said innovators should be open to anything, ready to participate in anything. Another said innovators should be 'open-minded and interested in other things that are going on so they are ready to contribute, mix.' Managers also had a range of views about what education was optimal for innovation.

Education for Innovators

All managers said innovators need a university qualification in a technical discipline like science or engineering, but one director said, 'There's some debate about whether that is right because we have people who are very good innovators, managers, even directors who don't meet those qualifications. Three business unit managers of the largest groups only have a [technical school] diploma.' One business unit manager felt a university degree was better than a technical school qualification because 'it implies more knowledge and more personal commitment and it looks better on a *cv*.' (*Curriculum vitae* are sent out with proposals when seeking new clients.)

There is some disagreement about the value of graduate qualifications. One director said a second degree was necessary while another said graduate qualifications were preferable and a third reported PhD. graduates 'have been the best from the point of view of having been trained to think analytically and creatively to solve problems. Usually people so equipped are capable of thinking along other lines and being diverse as well.' Another director concurred with the value of such skills but didn't say they came only from PhD. graduates. He said innovators' education had to make them good at 'finding out information and employing it in fields that are outside their experience rather than doing rote learned tasks of reproducing something.'

The next section tries to answer the question, what is the source of such characteristics? Can science educator create or encourage them in their students? It offers a philosophical rather than psychological or sociological answer that forms the basis for the suggestion that science educators can produce industry-valued innovators by encouraging scientific incompetence.

Technical Persons Versus Authentic Persons

Murdick (1969) describes a *technical person* as 'an individual with perceived competence or technical skill in a certain product or knowledge area, generally obtained from formal courses of specialised study (as distinguished from general academic education or from an apprenticeship)'.



Technical skills are said to encompass a general understanding of technical activities as well as the ability to apply methods and techniques to specialised areas. A ‘technical person’ seems a fair description of most scientists. The predominance of the word ‘specialised’ in this description is important to the following philosophical analysis.

Martin Heidegger (1977, 1996), whose philosophy is the foundation for this paper, has criticised scientists for their preference for representing the world in what he sees as a simplified and controllable form that lacks the practical complexity of what he calls *the public world*, the non-specialised, non-scientific world in which most people live. Heidegger says the knowledge of these simplified specialist worlds created by specialist scientific disciplines is ‘deficient’ in the sense that it lacks practical complexity and connection with the ordinary public world. (Heidegger 1996). Kuhn (1970) has likewise suggested that scientists operate in *different worlds* determined by their specialist paradigms, the implication being that these different worlds are not those accessible to the uninitiated. In addition, both Heidegger (1977) and Kuhn (1970) and many contemporary philosophers of science (Bijker, Hughes and Pinch 1987; Callon, Law and Rip 1986; Lynch 1993; Pickering 1992) have argued that science prescribes perspectives and practices that generate faith in the knowledge and methods produced through them. This makes it unlikely that scientists will leave their different worlds or seek affirmation in the public world. Resistance to industry input into education and research priorities is a reflection of this rejection of the public world’s relevance to science. And finally, Kuhn (1970) in particular has emphasised the dire consequences of moving outside one’s paradigm. Exclusion from the specialist community and loss of all credibility, he says, are the prices paid for violating what Heidegger (1977) calls ‘binding adherence to the rule and law’ of one’s speciality. This is why I say it takes courage to be incompetent, to question or transgress one’s scientific paradigm. You lose your place in the discipline community and with it you lose your identity which is tied up with being a ‘good’ scientist. Wolf (1994, p. 53) illustrates this in relation to physics:

The real problem facing physics today is the arrogance of many physicists who have long been isolated from industry and the real world and who simply do not see addressing society’s needs as their province. Such physicists do not want to recognise anything different as ‘proper’ physics. If someone moves outside their narrow definition of physics, he or she has simply ‘left physics,’ and anyone thus diverted is rarely invited back.

I argue that science educators necessarily must indoctrinate their students into the specialised different world of science, preparing them to see and do science as prescribed, and enforcing the need for binding adherence if one wants to be seen as a ‘good’ scientist. In so doing, I suggest science educators create technical persons who may be ‘competent’ but who must also be inauthentic or professionally conformist to be so. Heidegger and Kuhn are not critical of science educators for indoctrinating science students into a scientific paradigm. Both Heidegger and Kuhn acknowledge the effectiveness of the scientific approach to knowledge-making. Delineating specialist realms of interest and prescribing approaches to them make research efficient and make cumulative progress possible. Technical persons are important to specialist knowledge-making and routine productivity.

But Kuhn (1970) especially points out that this approach does not encourage creativity, adventurousness or discovery. According to the consultancy managers cited above and many studies of innovation, these qualities are important to innovation. Further, innovators are not in the knowledge-making business. They are in the money-making business and the money to be made must be made in the public world, in what Heidegger (1996) refers to as the world of the ‘wearers and users’ of what is made and what business refers to as ‘the marketplace’.

While Heidegger is not motivated by such mundane concerns as money-making and market responsiveness, he is concerned about human potential and he sees the mandated conformity at the root of science as a danger to human potential because it prevents people being authentic, that is, it



prevents people existing in the world as unique and creative individuals, as their genuine nature allows.

In contrast to Murdick's technical persons, *authentic persons* are non-conformists who recognise their capacity to operate *sometimes* (not always) outside professional, cultural and social paradigms. Authentic persons are characterised by 'resoluteness,' a kind of decisiveness based on seeing some situations as offering unique and special possibilities for action. Authentic persons also take responsibility for the decisions they make. Further, authentic persons value their individual freedom but, in contrast to self-centred *individualists*, authentic persons also respect the individuality of others which makes them cooperative, team-oriented and open to the alternative perspectives of others. Authentic persons are also more likely to be in tune with the public world because of their practical (ordinary) rather than theoretical (specialist) orientation to the world (Heidegger 1996). Common examples of authentic individuals that appear in Heidegger's texts are craftspeople, traditional farmers, artists and poets (Heidegger 1971). More strikingly, these characteristics of authenticity are the qualities and attitudes that emerged from the innovation consultancy study and innovation literature. But they are not the characteristics one associates with scientific competence. Hence, I suggest they are the characteristics of incompetence.

The qualities of authenticity and inauthenticity are not permanent and defining characteristics of individuals. There are no authentic or inauthentic people. Each situation or experience, especially any problematic one that prevents people operating on 'automatic pilot,' requires people to *decide* whether they will be authentic or not (Heidegger 1996). Authenticity or inauthenticity is a momentary existential choice we make many times a day. The possibility of deciding is the basis for the suggestion that science educators can develop the capacity for incompetence/authenticity in their students. They can show their students that they have choices to make, that they are not bound by the precepts of the paradigm of science practice.

Teaching Incompetence/Inauthenticity

Numerous studies document organisational success in nurturing and encouraging authenticity in technical persons in the workplace (Cooper and Hartley 1991; Ehin 1995; Mathieu and Zajac 1990; Spencer 1995; Story 1995). Among the most common management approaches that encourage innovation is to require cooperation and communication across specialties and functions and to value daring, risk-taking and error as learning tools. Such approaches are directed to encouraging and rewarding authenticity/incompetence.

Few studies deal with how to encourage authenticity in science students, although the Australian Review of Engineering Education (Simmons and The Task Forces of the Review of Engineering Education 1996) pointed the way. On the basis of understanding competence as committed paradigm practice, science educators might encourage authenticity by encouraging incompetence. They could do this by undermining their students' *blind* commitment to the science paradigm. There is no better time to do this than just before students venture out into their professional communities. According to Kuhn (1970), the young and inexperienced are the least committed to their paradigm which makes them most likely to transgress the bounds of their paradigm. But how, without destroying the science profession, can science educators undermine the very commitment to a paradigm they must first create to transform science students into skilled technical persons?

The key to teaching incompetence is to remember that authenticity/incompetence is always about situation-specific choice, not about prescriptions. Science educators can prepare students to *decide* when to be 'good' scientists and work by the book or when to be incompetent and throw the book away for a time. They can show students their range of choices and how to evaluate those choices. To do this, students need an opportunity to critically reflect on and debate the beliefs, practices and values of the science paradigm so they understand the historical and situational nature of its knowledge and doctrines and the limits of its vision and prescriptions.



They also need to be exposed positively to other industry relevant paradigms—business paradigms, human communication paradigms, consumer paradigms, political paradigms, economic paradigms, social and environmental paradigms. And they must be exposed to the practical problems of abandoning one's paradigm or failing to do so when appropriate. They need to understand the dangers and rewards of being incompetent.

Rounding out a science student's education with a final semester capstone seminar that reads and discusses government policy papers on innovation and hears from industry R&D managers, marketers, venture capitalists and professional communicators who challenge what they've been learning or cast it in a new light could be an existentially liberating experience for students who are thereby encouraged to find their courage to be incompetent. Such a seminar might also be a good way to establish that even a quite conventional science education course could 'meet the needs of industry,' the magic words to unlock all those extra student places.

References

- Bijker, W., Hughes, T. and Pinch, T., (Eds)(1987) *The social construction of technological systems: New directions in the sociology and history of technology*. Boston: MIT Press.
- Callon, M., Law, J. and Rip, A. (1986) *Mapping the dynamics of science and technology: sociology of science in the real world*. London: The Macmillan Press.
- Cooper, J. and Hartley, J. (1991) Reconsidering the case for organisational commitment. *Human Resource Management Journal*, **1**(3), 18-32.
- DeNovellis, R. (1992) Technical people, technical management and successful management—What are the challenges? *Journal of Clinical Engineering*, **17**(6), 481-486.
- Department of Education, Science and Technology (2001) *Backing Australia's future: an innovation action plan for the future*. http://backingaus.innovation.gov.au/docs/statement/backing_Aust_ability.pdf.
- Ehin, C. (1995) The ultimate advantage of self-organising systems. *Journal of Quality and Participation*, **18**(5), 30-38.
- Hacking, I. (1992) The self-vindication of the laboratory sciences. In Andrew Pickering (ed.), *Science as practice and culture*. Chicago, IL: The University of Chicago Press, 29–64.
- Heidegger, M. (1971) *Poetry, Language, Thought*. trans., Albert Hofstadter. New York: Harper and Row.
- Heidegger, M. (1977) The age of the world picture. *The question concerning technology and other essays*. trans., William Lovitt. New York: Harper and Row.
- Heidegger, M. (1996) *Being and time*. trans., J. Stambaugh. Albany: State University of New York Press.
- Hinterhuber, H.H. and Popp, W. (1993) What makes a strategist out of a manager? What engineers should know about strategic management. *International Journal of Production Economics*, **303**(1), 297-307.
- Howard Partners (2003) *Evaluation of the cooperative research centre programme*, conducted for the Department of Education, Science and Technology.
- Kanter, R. (1988) When a thousand flowers bloom: Structural, collective and social conditions for innovation in organizations. In B. Staw and L. Cummings (Eds). In *Research in organizational behaviour*, Greenwich: JAI, 169-211.
- Kuhn, T. (1970) *The structure of scientific revolutions*. Chicago: University of Chicago Press.
- Lynch, M. (1993) *Scientific practice and ordinary action*. Cambridge: Cambridge University Press.
- Makino, N. (1987) *Decline and prosperity: Corporate innovation in Japan*. Tokyo: Kodansha International.
- Mathieu, J. and Zajac, D. (1990) A review and meta-analysis of the antecedents, correlates and consequences of organisational commitment. *Psychological Bulletin*, **108**(2), 171-194.
- Mogee, M. (1993) Educating innovation managers: strategic issues for business and higher education. *IEEE Transactions on Engineering Management*, **40**(4), 410-417.
- Murdick, R. (1969) Engineer as executive. N. Chironis (Ed) *Management guide for engineers and technical administrators*. New York: McGraw-Hill.
- National Research Council (1995) *National Science Foundation Convocation on Undergraduate Education*. Arlington: NRC Centre for Science, Mathematics and Engineering Education and Training.
- Nonaka, I. (1990) Redundant, overlapping organization: A Japanese approach to managing the innovation process. *California Management Review*, **32**(3), 27-38.
- Pickering, A., (Ed) (1992) *Science as practice and culture*. Chicago: University of Chicago Press.
- Robertson, A., Achilladelis, B. and Jervis, P. (1972) *Success and Failure in Industrial Innovation: Report on Project SAPHO*. London: Centre for the Study of Industrial Innovation.
- Schon, D. (1963, March/April) Champions for radical new inventions. *Harvard Business Review*, 77-86.
- Simmons, J. and The Task Forces of the Review of Engineering Education (1996) *Changing the Culture: Engineering Education into the Future*. Barton: Institution of Engineers.
- Spencer, R. (1995) Success in self-managed teams and partnering. *Journal of Quality and Participation*, **18**(4), 48-53.
- Steiner, C. (1996) *Magic Moments: A Phenomenological Investigation of the Role of Authenticity in Innovation*, PhD Dissertation, University of Melbourne Department of the History and Philosophy of Science, Melbourne.



Story, M. (1995) The secrets of successful empowerment. *National Productivity Review*, **14**(3), 81-90.

Thompson, R. (1993) Integrated design by design: educating for multidisciplinary teamwork. In *Proceedings 1993 SPE Annual Technical Conference and Exhibition*, 93-99.

Wolf, W. (1994) Is physics education adapting to a changing world? *Physics Today*, **47**, 46-55.

© 2004 Carol J. Steiner.

The author assigns to UniServe Science and educational non-profit institutions a non-exclusive licence to use this document for personal use and in courses of instruction provided that the paper is used in full and this copyright statement is reproduced. The author also grants a non-exclusive licence to UniServe Science to publish this document in full on the Web (prime sites and mirrors) and in printed form within the UniServe Science 2004 Conference proceedings. Any other usage is prohibited without the express permission of the author(s).



Visualising the science of genomics: cognitive and social interactions that promote learning in an online collaborative research project

Kathy Takayama, School of Biotechnology and Biomolecular Sciences,
The University of New South Wales

Abstract: *Visualising the Science of Genomics (VSG) is an open inquiry-based approach to enable students to experience the thrill of collaborative scientific research in the field of genomics. The primary goal of VSG was to engage students in the dynamic process of scientific inquiry using a multidisciplinary approach in an online environment. Students worked in teams to analyse, hypothesise, reflect, predict, and formulate models based on genomic sequence data from the Human Immunodeficiency Virus-1 (HIV-1), the causative agent of AIDS. Contextual relevance was provided through the creation of case studies based on actual data. The goal of VSG was to allow students to assess and interpret available information, and to develop their own research questions and methodology. VSG emphasised the process of investigation, facilitating students' metacognitive awareness of the scientific approach. The VSG project provided not only an inquiry-based approach to facilitate open-ended research, but developed a sense of ownership in students and resulted in the creation of a global online research community through multidisciplinary collaboration.*

Introduction

The international research project Visualising the Science of Genomics (VSG) engages students in the active process of collaborative scientific inquiry. The project was conducted entirely online amongst geographically distanced participants who worked in 'research teams' of five students, each from a different country. The project was trialled for a two-week pilot to investigate the pedagogical potential of a fully online research community. Participants represented a diversity of scientific backgrounds including: microbiology; bioinformatics; medicine; chemical engineering; biotechnology; pharmaceutical sciences; molecular biology; medical chemistry; genetics; biochemistry; mathematics; and computer science. The international and multidisciplinary composition of each research team provided the context for scientific research as a concerted global effort dependent upon contributions by scientists with specific areas of expertise.

The VSG approach aims to break from the traditional university laboratory practical, which, in dictating the 'aim of the experiment' and the predetermined methodology, omits a significant aspect of the student learning experience. In principle, the laboratory introduces the student to the practice of biology, whereby the learner is provided with the opportunity to apply his/her theoretical knowledge. One of the goals of the biology educator is to teach students how to 'think like scientists'; we aim to engage the student in a cognitive apprenticeship as a researcher. Paradoxically, in most laboratory courses the laboratory manual specifies the 'aims' or 'hypotheses', and the student follows an established protocol to conduct the experiment. A true cognitive apprenticeship, however, must include development of the thought processes that facilitate the formulation of a hypothesis, as well as the reasoning processes invoked in the development or application of appropriate methodology to test the hypothesis. Hence whilst technically the laboratory provides a tangible context, focus on content and outcome may override learning how. The VSG project endeavoured to foster authentic inquiry through the creation of a research community whereby knowledge was synthesised through collaborative investigation.

In view of the diverse backgrounds of the participants, preliminary information was sent to all participants prior to the start of the project. The information included background reading on HIV-1 as well as a CD-ROM tour and necessary technical information for the online work. The students were also encouraged to post brief introductions about themselves in their team sites to initiate students into the social framework of their learning community. The VSG student community was exceptionally diverse, consisting of students from different scientific majors, levels of study, and

cultural and ethnic backgrounds. The international and multidisciplinary composition of each research team was reflective of how scientific research is indeed a concerted global effort dependent upon contributions from partners with specific areas of expertise.

After receiving their individual case studies, the teams faced the challenge of developing their own research question(s) and appropriate methodology for investigation. Unlike most courses encountered in their academic careers, instead of being prescribed an ‘aim’ and corresponding protocol for their experiment, the students’ initial (and most difficult) pursuit was ‘what is my question?’ Furthermore, the students were not constrained by the need to derive a ‘correct answer’, for the emphasis of VSG was on process via the open-ended learning experience, and not on results.

Since we are given only the case studies, [they] provided us [with] a better opportunity to research into different aspects with the given data instead of madly following instructions from lecturers without understanding. The process of asking ‘why’ in the whole research project is important which usually disappears in the case if all of the instructions are given and [the] student is just a ‘follower’. *(student quote from feedback evaluation form)*

Despite the brief timeframe of the pilot study, a strong sense of community and ownership developed amongst the students as the temporal and geographical differences fostered a dependency on online collaboration. The intensity of this community and the bond developed between them and the instructor was surprisingly strong considering the groups were together as a community for only two weeks. The learning outcomes from this group of students were of an exceptionally high calibre.

Approach and Results

The cognitive/social interactions were assessed by examining the dialogic interactions in three areas (interfaces) of the VSG environment: Discussion and Feedback; (D and F); Chat; and Message Board). The schematic below (‘VSG online interaction’) represents the possible avenues of dialogic interaction amongst students, and between students and instructor (tutor) in the VSG community.

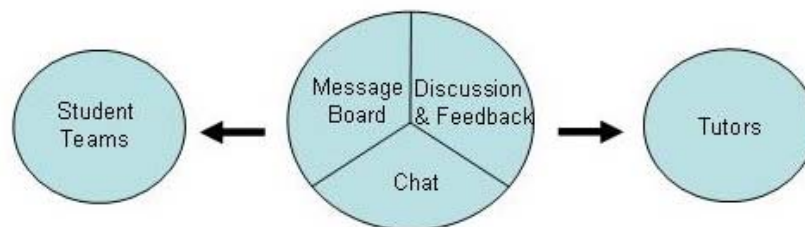


Figure 1. VSG Online interaction

Data were collected in the form of complete transcripts from each of these interfaces. Initial detailed cognitive assessment of student interactions in this community revealed that the social interactions were oft inherently linked to the synthesis and application of new knowledge. It became apparent that assessment of the interactions leading to the learning outcomes required integration of this observation into the methodology. Rubrics were therefore developed to categorise both the: a) social; and b) cognitive interactions that occur in VSG.

Analysis of social interactions in the VSG community

According to Shaffer and Anundsen (1993), ‘community’ is defined as a dynamic entity that emerges when a group of individuals share common practices, are interdependent, make decisions jointly, identify themselves with something larger than the sum of their individual relationships, and make a long-term commitment to well-being (their own, one another’s, and the group’s). The online community is dependent upon these same attributes in the absence of face-to-face contact or a voice. Indeed, the initial challenge of a project like VSG is the development of the community itself, as learning goals are concurrently being frameworked.

The rubric for assessing social interactions was developed based on Sringam and Geer's Cognitive Development Interactive Analysis Model (Sringam and Geer 2000), with the inclusion of an additional category, 'socialisation'. The seven categories in the modified Sringam and Geer rubric were as follows:

- socialisation;
- planning;
- sharing/comparing/contributing information;
- identifying or clarifying inconsistency of ideas, concepts or statements;
- negotiation of meaning/co-construction of knowledge;
- testing and modification of proposed synthesis or co-construction of knowledge; and
- agreement statement(s) and application of newly constructed knowledge.

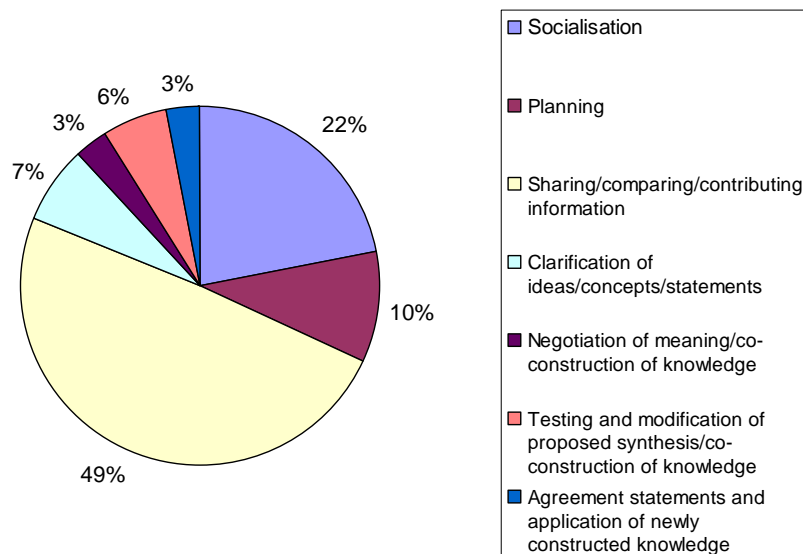


Figure 2: Categories of social interactions amongst students in VSG Discussion and Feedback

The two main categories of social interaction were: i) socialization; and ii) sharing, comparing and contribution of information. Whilst socialisation (22% of interactions) plays a significant role in facilitating collaborative learning, task-related interactions (78%) were predominant in the VSG community. This is indicative of student commitment and strong involvement in the investigation. Furthermore, a common observation amongst the groups was the negotiation and development of a shared understanding re: 'the problem' (task). While this sometimes took the majority of the students' time during the 2-week project, this process was in itself a conduit toward cognitive development. This is evidenced by the dialogic progression within a group that resulted in continual reflection and process-oriented critical analysis.

Being able to direct our own investigation was a little unnerving at first (it is a learning style that I am not used to), but I came to realize that this learning technique gave me a sense of pride; I had ownership of my data. This sense of pride and ownership motivated me to work hard to understand the problem as much as I could in the time available. (*student quote from feedback evaluation form*)

The social interactions in the VSG community were integral to the collaborative learning efforts of its members. Palloff and Pratt (1999) stress the importance of the development of shared goals that are related to the learning process in an online community. The integration of these goals into the social dialogue amongst the VSG students was indeed reflective of this engagement.

Collaboration is perfect when team members can almost read each others minds. I have experienced it before and I feel it takes a lot of communication and getting to know each other for team momentum to build up, but it’s a wonderful thing when it does happen. *(student quote from feedback evaluation form)*

Analysis of cognitive interactions in the VSG community

One of the key criteria for an authentic learning experience is that of fidelity of context (Meyer 1992; Wiggins 1993; Reeves and Okey 1996; Herrington and Herrington 1998). For many of my students, it was the first time in their academic careers that they found themselves immersed in collaborative authentic inquiry, whereupon they were driven by intrinsic motivation.

The freedom to take the investigation in any direction has been quite good, as it allowed flexibility *(student quote from feedback evaluation form)*

The rubric for assessing cognitive interactions was based on Biggs’ and Collis’ Structure of Observed Learning Outcomes (SOLO taxonomy) (Biggs and Collis 1982). The majority of the interactions as assessed via SOLO taxonomy were indicative of higher levels of cognitive ability (relational and extended abstract).

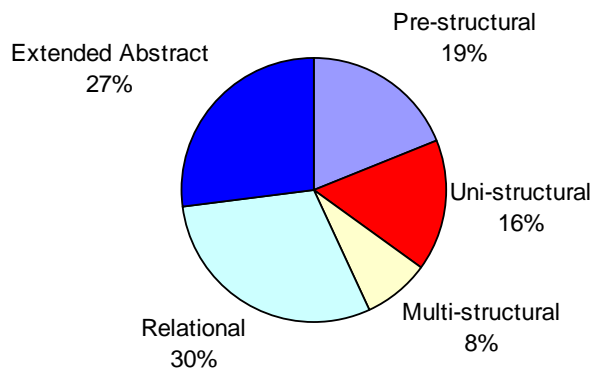


Figure 3. Cognitive assessment of student interactions in VSG Discussion and Feedback by SOLO taxonomy.

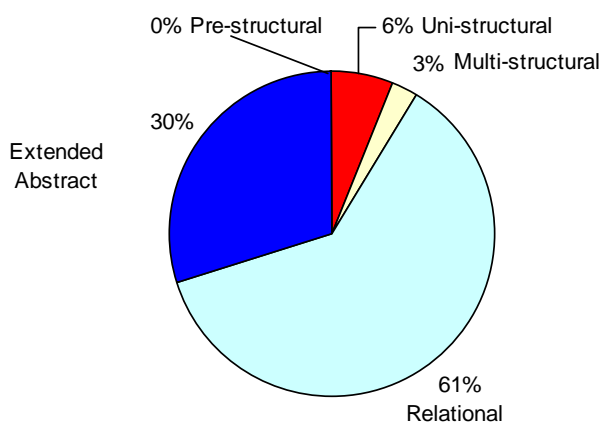


Figure 4. Cognitive assessment of student interactions in VSG Chat by SOLO taxonomy

Student discussions were characterised by analytical, contextual, and social dialogue. The instructor provided feedback and facilitation when appropriate. Whilst most teams initially performed similar preliminary ‘experiments’, the defined goals, specific datasets chosen, and strategies developed by the teams varied. This diversity of approaches exhibited by teams to develop their ‘question’ and ‘process’ may be reflective of the different perspectives, analyses, and expertise provided by the members of each research team.

The cognitive levels of interaction in VSG were higher than that observed in the instructor's classroom teaching. Whilst this may be due in part to the calibre of students that have volunteered to participate in this project, the approach utilised was characterised by several qualities that may also have strongly contributed to the learning outcomes:

- student-centred collaborative approach;
- open-ended scientific inquiry process;
- the creation of a strong online community of students and instructor; and
- contextual visualisations.

Charlin and colleagues (Charlin, Maun and Hansen 1998) emphasise a learner-centred approach towards problem-solving as being of key importance, and define four principles related to their effect on learning:

1. Learners are active processors of information;
2. Prior knowledge is activated and new knowledge is built on it;
3. Knowledge is acquired in a meaningful context; and
4. Learners have opportunities for elaboration and organisation of knowledge.

These principles are indeed reflective of the importance of contextual relevance for students who are presented with an abstract concept like genomics (Chinn and Malhotra 2002; Tobias and Hake 1988). The dialogue amongst students and between student and instructor revealed that the principles were indeed effectively utilised.

Analysis of the instructor's role in VSG

The instructor in a student-centred learning environment takes on new roles that are crucial in maintaining an interaction and collaboration amongst students. Technology-based learning communities like VSG where learning is dependent upon a socially interactive and collaborative experience are guided by a social constructivist approach to teaching and learning (Blanton Moorman and Trathern 1998; Duffy and Cunningham 1996; Jonassen and Reeves 1996; Maor and Taylor 1995; Tobin 1993). Student cognition via a social constructivist approach takes place within a social context and collaboration is an essential component. In such an environment, the instructor functions in several capacities: pedagogy; social interaction; management and technology (Bonk, Kirkley, Hara and Dennen 2001). Initial analysis of the instructor's contributions toward student team discussions revealed that my role as facilitator/motivator was nearly as prevalent as my pedagogical role (see Figure 5). This is markedly distinct from what occurs in face-to-face teaching. Reflections on this evidence of the various functions I fulfilled in this online community will formulate a more metacognitive approach for future projects.

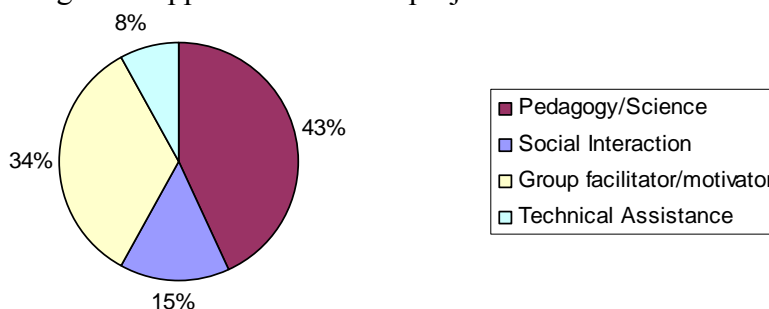


Figure 5. Roles of the instructor in the Discussion and Feedback forum

Reflections on metavisual cognition

One of the components of the VSG project was the integration of visualisations into contextual learning. The students were able to comprehend, analyse and apply abstract concepts through visual application of this abstract information. During the analysis of dialogic evidence, it became apparent that visual literacy would have played a significant role in student learning. Differences in the metavisual cognitive ability of the students would affect their ability to interpret and manipulate visual representations of their data.



Yes. Personally I understand things more readily through pictures and graphical representation, so I think Protein Explorer and Biology Workbench helped a lot in my understanding of genomic data. (*student quote on feedback evaluation question: Did the use of visualisation tools such as Protein Explorer and Biology Workbench facilitate your understanding in the application of genomic data? Please elaborate.*)

While chemistry educators have extensively characterised student visuospatial abilities and student learning (for example see Wu and Shah 2004 and references therein), this is an area seldom considered in teaching in the biological sciences. According to Christopherson (1997), visual literacy includes the ability to interpret and comprehend the meaning and significance of visual representations, effective communication through the application of the basic principles and concepts of visual design, the production of visual messages through appropriate technologies, and the application of visual thinking toward problem-solving. Students' metavisual competence may differ significantly within the context of a project like VSG. I would venture to propose that metavisual competence in the area of genomics encompasses the following practices:

- recognition and comprehension of modes of visual representation of genomic data;
- communication of genomic information through visual representation;
- comparative application of visual representations between sets of genomic data;
- transfer of genomic information from one visual mode of representation into another visual mode of representation;
- development of models representing relationships based on quantitative and/or qualitative comparisons of visual genomic data analysis; and
- predictions of behaviour of new genomic data based on previous visual models.

These skills are gradually acquired through active experience in genomics research, whereby the researcher's understanding evolves as knowledge is synthesised within appropriate contexts. However, the learner who does not have the opportunity to access this experiential learning must develop these metavisual skills through alternate frameworks that are often subject to limitations of time and resources. To ultimately facilitate visual literacy at this level, it is imperative to ensure that the process is appropriately scaffolded by assessing competence in 'prerequisite' visual literacy in the genomic context. That is, in order to perform cognitive operations in a spatial domain, the learner must be competent in the visuospatial skills that are required for each of the conceptual steps that comprise genomics visual literacy.

In summary, emphasis on the process of inquiry through open-ended collaborative projects like VSG can facilitate students' metacognitive awareness of the scientific method. The collaborative effort was further strengthened through the creation of an online learning community that reflected a constructivist approach to teaching. Furthermore, metavisual cognition is a process that needs to be developed in parallel with scientific cognitive scaffolding; this may be an increasingly significant issue to be addressed in consideration of the challenges we face in employing visual representations of information-rich data when teaching genomics and related topics in systems biology.

References

- Biggs, J.B., and Collis, K.F. (1982) *Evaluating the Quality of Learning: the SOLO Taxonomy*. New York: Academic Press.
- Blanton, W.E., Moorman, G., and Trathern, W. (1998) Telecommunications and teacher education: a social constructivist review. *Review of Educational Research*, **23**, 235-275.
- Bonk, C., Kirkley, J., Hara, N., and Dennen, V. (2001) Finding the instructor in post secondary online learning: pedagogical, social, managerial, and technological location. In J. Stephenson (Ed) *Teaching and learning online: Pedagogies for new technologies*. 76-98. London: Kogan Page.
- Charlin, B., Mann, K., and Hansen, P. (1998) The many faces of problem-based learning: A framework for understanding and comparison. *Medical Teacher*, **20**(4), 323-330.
- Chinn, C.A., and Malhotra, B.A. (2002) Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, **86**(2), 175-218.



- Christopherson, J.T. (1997) The growing need for visual literacy at the university. Paper presented at the Visionquest: Journeys toward visual literacy; *28th Annual Conference of the International Visual Literacy Association*, Cheyenne, WY.
- Duffy, T.M. and Cunningham, D.J. (1996) Constructivism: implications for the design and delivery of instruction. In D. H. Jonassen (Ed) *Handbook of research for educational communications and technology*, (170-198). New York: Macmillan.
- Herrington, J., and Herrington, A. (1998) Authentic assessment and multimedia: how university students respond to a model of authentic assessment. *Higher Education Research and Development*, **17**(3), 305-322.
- Jonassen, D.H., and Reeves, T.C. (1996) Learning with technology: using computers as cognitive tools. In D. H. Jonassen (Ed) *Handbook of research for educational communications and technology*. (693-720). New York: Macmillan.
- Maor, D. and Taylor, P.C. (1995) Teacher epistemology and scientific inquiry in a computerised classroom environment. *Journal of Research in Science Teaching*, **32**, 839-854.
- Meyer, C.A. (1992). What's the difference between authentic and performance assessment? *Educational Leadership*, **49**, 39-40.
- Palloff, R.M., and Pratt, K. (1999) *Building Learning Communities in Cyberspace*. San Francisco: Jossey-Bass.
- Reeves, T.C. and Okey, J.R. (1996) Alternative assessment for constructivist learning environments. In B. G. Wilson (Ed.), *Constructivist learning environments: case studies in instructional design* (191-202). Englewood Cliffs, NJ: Educational Technology Publications.
- Shaffer, C. and Anundsen, K. (1993) *Creating Community Anywhere*. New York: Jeremy P. Tarcher/Perigee Books.
- Sringam, C. and Geer, R. (2000) An investigation of an instrument for analysis of student-led electronic discussions. Paper presented at the Learning to Choose, *ASCILITE 2000 Conference*, Coffs Harbour, NSW, Australia.
- Tobias, S., and Hake, R.R. (1988) Professors as physics students: What can they teach us? *American Journal of Physics*, **56**, 786-794.
- Tobin, K. (1993) Constructivist perspectives on teacher learning. In K. Tobin (Ed) *The practice of constructivism in science education*. Hillsdale, NJ: Lawrence.
- Wiggins, G. (1993) Assessing student performance: Exploring the purpose and limits of testing. San Francisco, CA: Jossey-Bass.
- Wu, H.K., and Shah, P. (2004) Exploring visuospatial thinking in chemistry learning. *Science Education*, **88**, 465-492.

© 2004 Kathy Takayama.

The author assigns to UniServe Science and educational non-profit institutions a non-exclusive licence to use this document for personal use and in courses of instruction provided that the article is used in full and this copyright statement is reproduced. The author also grants a non-exclusive licence to UniServe Science to publish this document in full on the Web (prime sites and mirrors) and in printed form within the UniServe Science 2004 Conference proceedings. Any other usage is prohibited without the express permission of the author.