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ABSTRACT

A number of strategies, informed by science education research, have been identified to assist the understanding and communication of difficult concepts in science. A teacher's craft lies in creating learning experiences that facilitate concept development and challenge misconceptions from which students actively build, modify, and extend their conceptual understanding. Concept mapping is accepted as one of several research and evaluation tools that are valid devices for assessing conceptual change. Concept mapping has also been identified by teachers and researchers as a tool for assisting teachers to organize their teaching strategies. Conceptual understanding is influenced by the prior knowledge brought by students to learning situations. Effective teaching entails recognizing students' prior knowledge including any alternative frameworks and adopting teaching strategies to acknowledge those frameworks. Scientific facts, if learned in a meaningful, rather than rote, manner produce much in students' minds. Having identified their students' prior learning, educators are then faced with the challenge of creating learning experiences to facilitate meaningful learning and conceptual understanding. Meaningful communication of concepts can be taught through the use of contexts and case studies; discrepant events (when a mismatch exists between the preconceptions that students bring to a learning situation); analogies, metaphors, and similes; examples and non-examples; and multiple representations of verbal and nonverbal information. Four tables and two figures illustrating aspects of the various teaching methods are included. (Contains 36 references.) (RS)

What science education really says about communication of science concepts

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Introduction

While browsing in the Jackson Street Used Book Store in downtown Athens, Georgia, USA, the title of a book caught my eye: *'What Darwin really said'*. On the debit side, purchase of yet another book would add to my already overweight luggage; on the credit side, the book would usefully add to my professional library and even partner a book entitled *'What Darwin saw'*. An unanticipated credit is that it has provided the basis for the title of this paper. Further, while Charles Darwin is best known for his articulation of the role of natural selection in evolution, we will see later that he also had something to say about teaching and learning.

In any society, information is a valuable commodity, whether it be declarative knowledge ('knowing that'), procedural knowledge ('knowing how') or strategic knowledge ('knowing why/when to'). The essential nature of information is highlighted by the resources that are committed to its handling in our society, including information storage through library and archive systems, information transfer and dissemination through communication systems and information acquisition and understanding through formal educational systems. Educators and journalists are both players in an information game that involves third parties - student learners in the case of educators and readers/viewers in the case of journalists; both are contributors to the societal goal of a well-informed citizenry.

Views of science and its impact on science education

Science education research provides a rich and diversely patterned tapestry and it is from this tapestry that threads will be sampled in this presentation It is appropriate, at first, to provide a brief overview of the nature of science and of the constructivist framework in science education research that derives from this view of science.

Science education research has been influenced by philosophers of science, such as Kuhn (1962) and Lakatos (1970) whose writings challenged the objective and theory-free basis of scientific knowledge - the so-called empiricist-inductivist framework in which data collected in unprejudiced exploration dictate conclusions. These writings were the death knell of the so-called 'discovery' methods of learning that were premised on the assumption that simple, unprejudiced observations by students will lead to inductive generalisations. In this regard, Hodson (1988) commented:

> *'Rather than scientific knowledge deriving from content-free scientific processes, existing knowledge informs and determines the processes by which further knowledge is generated and validated.'*

A widely accepted basis of scientific knowledge is the hypothetico-deductive framework in which expectations guide collection of data that are shaped to fit preferred conclusions. From this perspective, science may be seen as a creative human activity that is guided by the preconceptions of practitioners and in which the formulation of questions and the collection of data are carried out in a subjective way. Donald Johanson, a well-known palaeoanthropologist, (Johanson & Edey 1981) reflected this perspective when he wrote:

> *'There is no such thing as total lack of bias. . . . The fossil hunter in the field has it. If he is interested in hippo teeth, that is what he is going to find, and that will bias his collection because he will walk right by other fossils without noticing them.'*

The power of preconceptions on observation is illustrated by the experience of the scientist, David Pilbeam, (cited by Lewin 1987). Pilbeam described how his original interpretation of a particular fossil was affected by his prior expectations:

> *'I "knew" . . . (the fossil), being a hominid, would have a short face and a rounded jaw - so that's what I saw.'*

In fact, subsequent discoveries showed that this fossil did not possess these anatomical features and was not a hominid.

Just as experienced scientists are influenced by their expectations and prior assumptions, students likewise come to learning situations neither cognitively passive nor conceptually pristine. No longer may learners be regarded as 'blank slates' onto which teachers faithfully transcribe new knowledge, or as 'empty vessels' into which teacher pour new knowledge to identical levels. Instead learners bring their prior knowledge to learning situations and this knowledge affects their subsequent learning.

Constructivism is a label given to the view that learners construct and reconstruct their knowledge of the external world and that their reflections, inquiries and actions determine that knowledge, as much as or more so than, the nature of the external world itself. (Consistent with the concept that it defines, constructivism has several flavours and interpretations!) Since learners are primary and active agents in the process of acquiring knowledge and constructing meaning from it, it follows that while the same message may be transmitted to a group from the hilltop (or in the newspaper or in the classroom), different messages are received by members of that group who may merge, ignore and transform parts of the transmission. While the labels used by each learner to identify knowledge are shared, the meanings of each label are idiosyncratic.

This constructivist framework:

- is a catalyst for an increased interest and research in areas such as the prior knowledge brought to learning situations by students since this prior knowledge is deemed to affect their learning;
- provides a rationale for the development of techniques for eliciting and representing learners' states of knowledge since learning should be reflected in changes in knowledge states.
  Obviously, students' cognitive structures can only be inferred, but use of relevant techniques, such as concept mapping and semantic features analysis, can provide some insight into the mental models held by students (see Jonassen, Beissner & Yacci 1993).
- gives an impetus to the formulation of teaching strategies that facilitate student understanding and conceptual change.

So, knowledge is not like a collection of pottery shards on an archaeological dig - objects in existence and waiting to be unearthed; rather, each learner's knowledge is moulded and constructed at his/her own cognitive potter's wheel. The teacher's role is to provide suitable clay and define the parameters of the object to be moulded.

No longer, then, is teaching simply a stage on which a teacher performs and, in so doing, actively transmits information that is received unaltered by passive learners. Instead, a teacher's craft lies in creating learning experiences that facilitate concept development and challenge misconceptions and from which students actively build, modify and extend their conceptual understanding. In the following section, these ideas will be further expanded, particularly with regard to declarative knowledge.

Concept development: learning in action

In the preface to his book *'Concepts, kinds and cognitive development'*, Keil (1989) tells of collecting at an early age a disorderly cluster of flowers for his mother who proceeded to cut the flower stems to the same length and carefully arrange the flowers in a vase. On showing the floral arrangement to her son, the mother said something about it being 'symmetrical'. Keil recalls that later, at kindergarten, he asked his teacher what 'symmetrical' meant only to be told that it was *'not the kind of word you can understand at your age'*. (He recalls pondering whether it was one of those 'naughty' words that only adults were allowed to use.) The teacher apparently judged the concept of 'symmetrical' to lie beyond the grasp of her young student and chose not to try to elucidate it for her young student.

In the classroom setting, biology teachers regularly face comparable challenges but typically do not have the option of simply stating to their students that concepts such as 'DNA profiling', 'gene splicing', 'trisomy-21' and 'gamete intrafallopian transfer' are *'not the kind of words you can understand at your ages'.* Among the several challenges that are prominent in the teaching and learning of biology are the need for learners to master abstract and complex concepts, and the need for teachers to present these concepts in a suitable manner. How might these be communicated? Can the efficacy of this communication be measured?

A view of the complexity of learning in a domain of science may be obtained by identify the verbal labels encountered by a student of genetics. Table 1 shows one type of categorisation of these labels. In addition to verbal labels of concepts, the student of genetics is confronted with other forms of representation of knowledge, including symbolic (for example, **CCTGAT**; ***AaBb***; **F8C**; **47,XY,+21**; **EcoRI**), algebraic/mathematical (for example, **f(Aa) = 2pq**; **9:3:3:1**), as well as images in the form of graphs, diagrams and pictures.

TABLE 1: Some categories of verbal concept labels in genetics

	LABEL CATEGORY	**Examples**
1	**familiar non-exclusive**	• dominant • transcription
2	**exclusive & simple**	• allele • codon
3	**exclusive & compound**	• restriction fragment length polymorphism • variable number of terminal repeats
4	**'parsimonious'**	• linked • recombinant
5	**redundant**	• parental / non-crossover • meiosis / reduction division
6	**similar sounding**	• mitosis/meiosis, • transcription/translation, • intron/exon.
7	**inconsistently used**	• sense & anti-sense strands of DNA • gene & allele

Regarding Table 1, category 1 labels may be a source of confusion because their everyday meanings, which are the first to be established, differ from their meanings in a genetic sense. Category 4 labels have different meanings depending on the identity of the objects that they qualify; for example, the meaning of linkage is different in 'X-***linked*** gene' & 'two ***linked*** genes'. At best, category 5 labels may create an overload; at worst, such labels may be interpreted differently. Category 6 labels have the potential for confusion and may not be discriminated by students.

In their study of biology, students form representations of knowledge and construct and reconstruct their own meanings as new information and experiences are encountered. The intention of teaching genetics is to develop in a learner's cognitive structure certain knowledge elements that are related in specific ways. The process that occurs in a learner whereby concepts become woven in a relational structure with other concepts is termed *concept development*. One model proposes that concept development occurs when new concepts become appropriately linked with concepts already held in the learner's cognitive structure or when concepts are realigned and reorganised or when existing concepts are replaced. Concept development has been investigated both within and across age groups in areas of science, including genetics (for example, Stewart & Dale 1989), evolution (Bishop & Anderson 1990), chemistry (Abrahams, Williamson & Westbrook 1994) and physics (Kesidou & Duit 1993).

Concept mapping is accepted as one of several research and evaluation tools that are valid devices for assessing conceptual change (for example, Wallace & Mintzes 1990; Markham & Jones 1994). Concept mapping has also been identified by teachers and researchers as a tool for assisting teachers to organise their teaching strategies (for example, Cliburn 1990).

Table 2 shows a list of concepts which relate to the content area of movement; this list was given to a group of teachers, none of whom had specific knowledge of anatomy and physiology, as part of introducing them to the use of concept maps to assess aspects of understanding. Following clarification of the technique of concept mapping, each teacher was invited to produce a concept maps using the listed concepts on an overhead transparency, and maps produced by the various teachers were later displayed anonymously to the group.

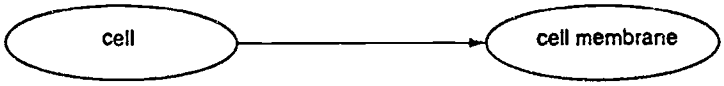
TABLE 2: Concepts related to movement

ligament	tendon	muscle
bone	joint	flexion
bursa	cartilage	synovial fluid
extension	nerve	abduction
adduction	contraction	relaxation
prime mover	antagonist	impulse

It is reasonable to suggest that the degree to which these concepts can be incorporated into a map with appropriate labels and directional arrows provides some insight to a person's knowledge of these concepts and of their inter-relatedness. It is also reasonable to suggest that the use of concept mapping prior to and following learning experiences can provide some insight to conceptual change that may have occurred in learners. The group of teachers, in light of their experience, endorsed these assertions.

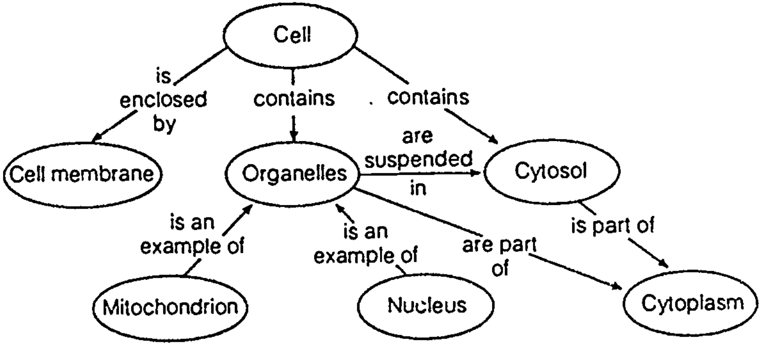
Figure 1 below shows an example of the use of concept mapping taken from questions at end of the first chapter of a textbook (Kinnear & Martin 1993); the topic of the initial chapter was 'Cells'. The question was intended to demonstrate to students how concept mapping is done and have them draw a simple map so that, at the end of each successive chapter, students might as a post-learning activity assess their own knowledge by map making using relevant keywords from that chapter.

1. **The key words listed above can also be called concepts. Concepts can be related to each other by use of linking words or phrases to form** propositions. For example, the concept 'cell' can be related to the concept 'cell membrane' by the linking phrase 'is enclosed by' to form a **proposition**. An arrow is drawn to show the sense of this relationship:



When several concepts are related in a meaningful way, a **concept map** is formed. Because concepts can be related in many ways, there is no single correct concept map.

Figure 1.19 shows one concept map containing some key words from this chapter.



Add to this map or prepare another concept map by using keywords from the list above or other words of your choice.

Prior knowledge & alternative frameworks

Conceptual understanding is influenced by the prior knowledge brought by students to learning situations. This prior knowledge is variously labelled as 'preconceptions', 'naive theories', 'alternative frameworks', 'untutored beliefs' and 'misconceptions'. The conceptions held by students in many domains have been identified; for example 'gravity' (Berg & Brouwer 1991), 'food chains' (Gallegos, Jerezano & Flores 1994), changes of state of matter (Stavy 1990).

Faced with a learning task, students are influenced by their preconceptions which may have arisen from their personal experience, from informal sources including everyday conversations, newspaper articles and television programs, and from prior formal educational settings. The conceptual understanding arising from these different experiences may not be concordant.

Consider the concept of 'fruit'. In everyday life, the defining criteria for this concept include taste, appearance and the meal course at which it is served. Even young children recognise apples, oranges and strawberries as 'fruit' and differentiate them from 'vegetables' such as peas and potatoes, from 'nuts', such as walnuts and almonds and from 'seeds' such as those of sunflower. As perceived by a botanist, however, the concept of 'fruit' is defined as a mature plant structure comprising a ripened ovary with its enclosed seeds. While botanical 'fruits' include apples, oranges, they also encompass the hard pips on a strawberry surface, some 'vegetables', such as tomatoes, peas and beans, some 'nuts', such as almonds and walnuts, and some 'seeds' such as sunflower seeds.

Both concepts of fruit are correct and simply reflect different definitions applicable to different contexts. In an everyday setting, such as planning a menu, it would be inappropriate to use the botanical concept of fruit. After ordering 'fruit salad & ice cream', dinner guests at a restaurant would be little impressed by a serving of ice cream with tomatoes, peas and sunflower seeds, regardless of the chef's botanical justification. Similarly, assessing the action of a chemical that arrests fruit development on a plant should be done in terms of the botanical concept of fruit, not the everyday one.

Alternative frameworks may exist in relation to the cause of commonplace events and experiences; for example: annual change of seasons (proximity of Earth to the Sun versus inclination of the Earth's rotational axis); sex determination (time of sexual intercourse versus sex chromosomal complement : XX or XY from parents); Down syndrome (viral infection during pregnancy versus trisomy-21). Other examples of alternative frameworks include dietary myths, such as the view that the positive value of vitamin supplementation (or an ingested medicine) is in direct proportion to dose size, or that margarine has less kilojoule per unit mass than butter. In these cases, alternative frameworks may impact negatively on people because the information base that informs their thinking and decision making is flawed. So, a couple who mistakenly hold the view that an inherited disorder cannot appear in the baby of two normal healthy people may, in that event, be drawn to explanations involving concealment of family medical history or infidelity.

Pre-existing alternative frameworks that do not accord with scientific concepts may be resistant to change and act as real barriers to learning (for example, Linn & Burbules 1988). It follows that, at the level of individual learners, effective teaching would entail recognising their prior knowledge including any alternative frameworks and adopting teaching strategies that acknowledge them. At the level of mass communication, acknowledgment of common misconceptions would appropriate. It should be noted, however, that some researchers (for example, Mathukrishna *et al.* 1993) have found that children's alternative frameworks change in response to a well-designed curriculum without these frameworks being explicitly addressed.

Meaningful versus rote learning

In 1862, Dr George Moberly, the headmaster at Winchester (cited in Barber, 1980) is reported to have told the Clarendon Commission on Education that

> *'a scientific fact, either as conveyed by a lecturer, or as reproduced in examination, is a fact which produces nothing in a boy's mind. It is simply a barren fact, which after a few years becomes confused with other facts and is forgotten. It leads to nothing. It does not germinate, it is a perfectly unfruitful fact.'*

No doubt he was referring to isolated scientific facts learned in a rote manner occurred at that time for Latin verb declensions and with students being rewarded for parrot-like repetition of relevant items.

Science educators would have no argument with the good Dr Moberly but would counter that, if learned in a meaningful, rather than rote, manner, scientific facts produce much in a boy's (and indeed in a girl's) mind. Moore (1988) commented on the paucity of value of isolated facts when he wrote that formal study (in science) should

> *'emphasize concepts and understanding over and above isolated facts and will leave students with a systematic program for thinking about the phenomena of the natural world in a disciplined manner'*

What is meaningful, in contrast to rote, learning?

- Meaningful learning, also referred to as 'active', or 'deep' or 'constructive' learning, involves active incorporation of new concepts by a learner who relates and links them to concepts already existing in the learner's cognitive structure.
- Rote learning, also referred to as 'passive', or 'shallow' or 'reproductive' learning, involves retention, with little or no comprehension, often for a just short time period; learning of this type assumes that the new concepts do not become linked to pre-existing concepts.

It did not take recent science education research to identify the shortcomings of rote learning. In his autobiography, Charles Darwin wrote the following about his days at Shrewsbury School:

> *'The school as a means of education to me was simply a blank. . . . Much attention was paid to learning by heart the lessons of the previous day; this I could effect with great facility, learning forty or fifty lines of Virgil or Homer, whilst I was in morning chapel; but this exercise was utterly useless, for every verse was forgotten in forty-eight hours.'* (p.16).

Commenting on his university experiences at Cambridge, Darwin also provided testimony to the need to learn meaningfully from a well-grounded foundation:

> *'During my three years at Cambridge, my time was wasted, as far as academic studies were concerned . . . I attempted mathematics . . the work was repugnant to me, chiefly from my not being able to see any meaning in the early steps of algebra.'* (p.27) .

Having identified their students' prior learning, educators are then faced with the challenge of creating learning experiences to facilitate meaningful learning and conceptual understanding.

Meaningful communication of concepts

a. Use of contexts

Without a context, the meaning of the following sentence may be difficult to interpret :

The sheet broke and the vessel tilted.

In fact, the use of 'sheet' here is in a nautical context where a sheet refers to a rope used to control the jib or foresail of a yacht.

One way to promote meaningful learning and concept development is through a context-based or case study approach. Suitable contexts provides a powerful means for engagement of a student's initial interest - a necessary, but not sufficient condition for learning. This engagement might be seen as corresponding in function to the eye-catching headline in the newspaper or the television teaser. At a simple level, context is provided in written texts through the use of chapter and sub-headings. Provision of a context sets a framework that assists the learner to impose meaning. However, it is important that, if a concept is introduced to learners in one context, assessment of their conceptual understanding occur in other contexts to ensure that the essence of the concept has been recognised.

Consider the following description that give contrasting approaches to the presentation of meiosis, the key mechanism whereby genetic information is packaged for transmission from parents to offspring.

A One approach might be context-free, focussing on the details of the process and requiring students to learn the names of the stages in the process and to reproduce relevant diagrams. Rewards might be given for assessment tasks involving faithful regurgitation of information. Such an approach would be expected to result at best in rote learning with students forging few, if any, links with related concepts. Instead, the students might temporarily hold some facts in Dr Moberly-type isolation, but would neither recognise the biological significance of the outcome of the meiosis nor the consequences of its operation, both normal and faulty. Little interest, little engagement, little real learning!

B An alternative approach to the same topic might provides an introductory context that reflects the operational outcome of the meiotic process, such as the case study of a normal child with a sibling affected by Down syndrome or the puzzle of the 'geep'- hoax or the true offspring of a sheep and a goat? These applied contexts which centre on the outcomes of meiosis would create a favourable climate for later exploration of the process of meiosis itself as a basis for explaining outcomes. Rewards might be given for assessment tasks involving application to novel situations. Greater interest, greater engagement, potentially greater real learning! (Would the newspaper headline read: 'Great 'geep' hoax exposed by meiosis!)

This latter approach is consistent with the so-called learning cycle method, one version of which comprises the following phases of student activity:

engagement; exploration; explanation; elaboration; and evaluation.

Science education research provides evidence that meaningful learning by students may be facilitated by other strategies that may be incorporated appropriately into teaching methods; these strategies include use of:

- discrepant events
- analogies
- examples and non-examples
- multiple representations.

b. Discrepant events: What's going on here?

Use of discrepant events, as described by Minstrell (1985), entails prior identification by students of their initial conceptions and subsequent exposure of students to a 'discrepant' event that is inconsistent with and contradicts their initial conceptions.

Use of this strategy is appropriate when a mismatch exists between the preconceptions that students bring to a learning situation and the relevant scientific concepts, such as the concept of 'fitness' in the study of evolution and the concept of 'dominance' as it relates to inherited traits. Ideally, the discrepant event sets up a conceptual conflict that is resolved as part of classroom debate and discussion. This is followed by consolidation of the new concept using additional and novel contexts.

Discrepant events may be generated by simple triggers, such as a short narrative or an image, or through laboratory activities, videodisc clips or computer simulations. Kinnear (1983), for example, used computer-based learning situations with genetic simulations to provide discrepant events that confronted students' inappropriate alternative framework concerning outcomes of particular matings. Active engagement by students in suitably designed activities was found to assist students in reconstructing the meanings of verbal labels.

c. Analogies: Seen a quoll (or was it a polecat) lately?

Early European explorers and settlers in Australia were mystified by the extraordinary animals they encountered that were quite unlike the familiar animals of their prior experience. Descriptions of Australian fauna by early European explorers and settlers (Table 3) provide some insight to how they made sense and created conceptual understanding through use of analogies that recognised similarities between familiar animals and the unknown animals of Australia, so building from the known to the unknown.

TABLE 3: Early European descriptions of Australian fauna.
(Key1: quokka; 2: kangaroo; 3: quoll; 4: wombats & koalas)

1 *'. . we found large numbers of a species of cats, which are very strange creatures; they are about the size of a hare, their head resembling that of a civet- cat . . . has five small nails or fingers, resembling those of a monkey's forepaw. . . its tail is very long, like that of a long-tailed monkey . . . clutches its food with its forepaws, just like a squirrel or monkey. . . Below the belly of the female carries a pouch.' (Pelseart, 1629)*

2 *'. . . of light Mouse colour and the full size of a greyhound and shaped in every respect like one, with a long tail which it carried like a greyhound, in short I should have taken it for a wild dog but for its walking or running in which it jumped like a Hare or a Deer . . . (Cook, 1770)*

3 *'. ., it is about the size and something like a polecat, of a light brown spotted with white on the back and white on the belly' (Banks 1770)*

4 *'Others again, though they have more the form of bears and badgers, and are slow and unwieldy in their motions, are something analogous to hares and rabbits (1829)*

Analogies involve comparisons of similar attributes between two otherwise dissimilar objects or concepts, one being familiar/concrete/macroscopic (the analogue) and one being less familiar/abstract/ microscopic (the target). The label 'analogy' typically includes formal analogies (*A is to B is as C is to D*), metaphors (*A is B*) and similes (*A is like B*).

In the domain of research, scientists have identified that use of analogies fosters creative insight and generates vivid imagery (Leatherdale 1974). Does this also apply to student learning?

Research has shown that the use of analogies assists students in constructing their meanings for new concepts (for example, Stavy 1991; Brown 1992). However, learning does not occur automatically through analogy use but requires that the relationship between the unfamiliar target and its analogue be made explicit. Use of analogies should optimally result in a mental transfer by the learner of shared attributes between the analogue and its target. However, since a target and its analogue are by definition different, use of analogies has the potential to result in learners transferring unshared attributes between analogue and target. Inappropriate similarities between analogue and target should be identified so that misconceptions are not generated (Spiro *et al.* 1989).

For impact in concept development, analogies should involve an element of attention-grabbing novelty that creates interest and stimulate the construction of new ideas. Analogies of this type are termed 'constructive'. In contrast, statements frequently heard and read by students such as:

Mitochondria are like the powerhouse of a cell
DNA is the blueprint of life

become rote in nature, are used as if literal and fail to help learners organise new meaning. Analogies of this type are termed 'dead' (Tiberius 1986).

In educational settings, both teacher- and student-generated analogies may be used, with the latter assisting students to clarify their understanding. Table 4 shows part of a question relevant to gene manipulation in a biology textbook (Kinnear & Martin 1993). While the outcomes of gene manipulation are visible in medicine, agriculture, the pharmaceutical industry, and legal settings, the associated technology at a molecular level is highly abstract. Recognising that analogies make knowledge manageable and make abstract knowledge more concrete, this question was intended to generate new insights and provide material to enable students to elaborate new concepts and link them to existing knowledge.

TABLE 4 Part of textbook question

(a) Identify a tool of the genetic engineer that might be seen as analogous to the following objects. Give a reason for your choice.

.... is like a photocopier because ....
.... is like a adhesive tape because ....
.... is like a scalpel because ....

(b) Things compared in an analogy have some similarities, but they are not similar in every way. For each analogy, describe one important way in which the items compared differ.

d. Examples and non-examples:

The use of examples is an effective means of placing flesh on a verbal label such as 'mammal', 'recessive trait'. Provision of a battery of examples of a particular concept, whether objects, events or processes. should allow learners to identify its defining features. As well as the defining features which are the essence of a concept, examples will include salient (but non-defining) features. For the concept of 'mammal', its defining features include: presence of mammary glands, covering or fur or hair over all or part of the body, presence of three bones in the middle ear, presence of a diaphragm. Salient features might include 'four legged', 'household pet'

The provision of non-examples can strengthen the use of examples. Analysis of non-examples allows learners to clarify concepts and distinguish essential defining features from non-defining salient features. Claude is an animal with four legs and is kept as a pet by a student. Could it be a mammal? Must it be a mammal? What about a wild animal without hind limbs that lives in the river flowing through a tropical rainforest? (Yes: dolphins live in the Amazon River.)

The use of Venn diagrams is one means of presenting examples and non-examples and can assist in clarifying the defining features of concepts and in distinguishing related concepts, such as asking students to draw Venn diagrams to accommodate the following concepts: 'vertebrate', 'mammal', 'primate', 'bird', 'reptile', 'hominid'.

e. Multiple representations: The thousand words <u>and</u> the picture

Human cognition deals with both language ('Look at the red flag!') and nonverbal objects and events (the red flag itself or the sound of the flapping of the red flag in the wind or the feel of the texture of the red flag).

According to the dual coding theory (for recent summary, see Paivio 1990), two cognitive systems exist for the coding and storage of information: a language system for the coding and storage of written and spoken language and an imagery system for nonverbal (symbolic) information. The language system deals with abstract and sequential information, while the imagery system deals with concrete and parallel information. The dual coding theory proposes that either one or both systems can be active in information processing. Both systems may be presumed to be jointly active when a verbal utterance, such as *'orange tabby cat with white socks'* causes a subject to form a mental image of a suitable coloured feline or when a image of a bird evokes the thought or utterance: *'That's a crimson rosella'.*

Use of two modes of presentation, verbal and visual, has been shown to have an additive memory effect in children and result in greater retention and recall (Vasu & Howe 1989) which implies meaningful learning. The dual coding theory provides a rationale for the use of both images and language in communicating concepts since it brings visual and verbal dual input and allows learner to construct both symbolic and iconic representations. Stewart (1985) stated:

> *'Images provide a rich expressive medium for thought that complements analytical reasoning and offers quicker, more unexpected jumps and corrections.'*

The first picture book for children *Orbis sensualium pictus* was illustrated by 150 woodcuts and was published in 1658. The Czech author, Comenius, wished to provide children with information about the world through simple language and pictures. The value of pictures according to Comenius lay in his belief that only when something has been grasped by the senses can language begin to explain it further. He stated:

> *'Pictures are the most intelligible books that children can look upon.'*

Not surprisingly, research has shown that for student across a range of age groups, images of all types used with text or oral presentations have a positive effect on learning. Images can enhance retention, recall and promote constructive thinking (for example, Levie & Lentz 1982, Winn 1982). This conclusion is premised on use of appropriate images suitably integrated into learning materials and/or activities. This, however, is not news to people in the world of media. Newspapers, magazines, television programs, films and advertisements stand in testimony to the power and persuasion of the carefully crafted combination of visual images and verbal text (written or spoken) in the communication of information at large.

A variety of images, static and dynamic, may be used to represent information - graphs, diagrams, photographs, computer animations, video images, cartoons. These images may be presented to learners through textbooks, computer screen, film, and typically are used in conjunction with verbal information, written and/or spoken. Learning activities may involve teachers asking students to conjure their own images.

An element that may be readily introduced to a learning situation by images is humour. Flannery (1993) has argued for use in a sparing manner of cartoons in the science classroom and proposes that *inter alia* cartoons can be a succinct way to make a point, to test understanding (Can you see the joke?), and to increase students' awareness of social and political implications of issues in science. Figure 2 shows use of a cartoon to explicate related but distinctive concepts, namely 'internal' and 'external' environments (Kinnear & Martin 1993).

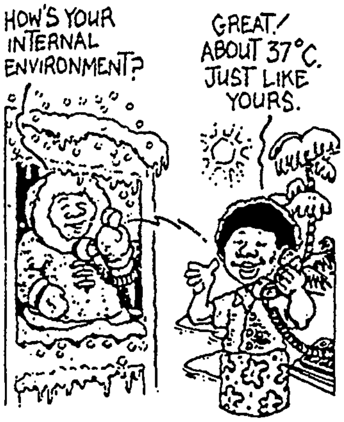


Figure 2: The concept of 'internal environment' which is normally regulated within a narrow range should be distinguished from that of 'external environment' which is changeable and can vary widely.

In learning environments, images can contribute to the achievement of intended learning outcomes. Images can provide representations of objects (cells, fruit), of processes (homeostasis, carbon cycle, anaerobic respiration) and of relationships (food web, energy flow through an ecosystem). Image can provide information that cannot easily be translated into verbal form; as for example, a distribution map showing the spread over time of an introduced exotic pest. Images can provide a concrete representations of abstract concepts, as for example, a computer-generated false colour image of a repressor molecule linked to the genetic material DNA. Images can capture in pictorial form, such as histograms and pie charts, numerical data that might otherwise be overwhelming to learners. Images can serve to provide, through re-scaling to familiar or more concrete forms, representations of objects or events whose temporal or spatial magnitude lie outside the normal experience of learners, such as the concept of a million, or the concept of geological time. Images may be used to provide different representations of the same object at various levels of resolution.

Images may also serve to:

capture a learner's attention
define a context
introduce a concept
explicate a concept
challenge a misconception
test understanding
provide representations at various levels of resolution
specify a social context
give example(s) & non-example(s)
pose a question.

In summary, a number of strategies, informed by science education research, have been identified to assist the understanding of difficult concepts in science. It does not follow , however, that strategies that are effective on a smaller scale in one context can be transferred to a larger scale different context.

Instead, this basket of strategies from the educational sector is put forward like goods at a garage sale for browsing by the communication sector.

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