Helping students to go SOLO: teaching critical numeracy in the biological sciences

David Lake
School of Education, Murdoch University, Western Australia

The majority of students are able to read data from graphs and tables, but many still have difficulty reading meaning into them. The SOLO taxonomy of Biggs and Collis can be adapted to provide a useful four-step template of generalized questions, that lead students from the basic skills of data retrieval, to the advanced skills of critical analysis.
Key words: Critical numeracy, Graphs, Tables, SOLO.

Introduction

The importance of critical numeracy in the biological sciences

While scientific understanding requires students to be familiar with the structure of scientific writing, they must also master the non-textual, quantitative conventions. Phenomenological research has provided some useful approaches for the former (see, for example, Weissberg and Buker, 1990), but the latter seems to be less well covered by the available literature. The ability to read, and more importantly interpret, graphs and tables is a fundamental skill for understanding science. It is 2 centuries since Lord Kelvin described physical knowledge that remained unamenable to mathematical modelling, as 'meagre and unsatisfactory' (Singer, 1959). While a less extreme position is adopted now, I frequently hear both secondary and tertiary science teachers complain that their students, while competent at finding the location of specific data, are unable to discern the important issues illustrated by graphs and tables. Graphs and tables are central to communicating biological research (Reynolds and Simmonds, 1981), and a scientific paper will often use one or two to summarise the entire research project (O'Connor, 1991). Secondary biological texts pay little attention to developing this vital area of critical numeracy. A quick survey of 25 popular, well-illustrated, upper secondary, biological textbooks published in the last 2 decades, uncovered less than one graph per chapter (almost none with more than one line), and even fewer tables. It is tempting to suggest that this type of material requires more active and reflective thought than fact-laden text, and is omitted because students have difficulty understanding its meaning.

Biological variation makes critical analysis of non-textual material arguably more pervasive and more taxing in the biological and social sciences than in the physical sciences (Beveridge, 1950). Comparisons involving many variables within one data-set are more common in the biological sciences than is normal in the physical sciences. Yet students' and teachers' perceptions of the biological sciences as 'softer' seems to stem, at least partly, from the assumption that their mathematical content is less demanding. It is true that mathematical manipulation and appreciation of formulae and symbolic equations requires different skills to those needed to understand graphic and tabular material (Halloun and Hestenes, 1985). However, these latter tasks require higher-order cognitive abilities to achieve the standards required by later secondary and early tertiary curricula (Shayer, 1972, 1974, 1978). In this context, it is important to differentiate between the ability to find specific information in a graph or table, the ability to comprehend the meaning of the same numeric material, and the ability to evaluate the validity of conclusions drawn from it. While teachers can expect the mechanical skills to have been developed during the student's mathematics training, it is less likely that the more subject-specific, higher-order, critical skills will have been developed in the same way. The biological science teacher must help their students to develop these higher-order skills.

Piagetian diagnostic tools

Piagetian epistemology provides a sound basis for the construction of curricula, and has been used extensively for this purpose over the last half century, particularly in science. The sequence of cognitive development, described by Piaget, reflects the development of scientific understandings, because of the close relationships between Western culture and the culture of science (Goodnow, 1980; Flavell, 1962; Lake, 1996). A feature of Piagetian epistemology is its stage-based approach, where each stage builds on the skills that were acquired at the previous one (Flavell, 1962). Although Piaget was concerned primarily with creating a science of knowledge, and the subjects in his studies were used to illustrate aspects of that, his work has been

Table 1 SOLO taxonomy descriptors (Biggs and Collis, 1982), and the general types of productive questions for each.

SOLO level	*SOLO descriptors*	*Focus for teacher's questions (exemplified in subsequent figures)*	
		Graphs	*Tables*
unistructural	Single relevant feature	What is the range of values? What are the maximum and minimum values?	What is the range of values? What are the maximum and minimum values?
multistructural	Listing relevant features	What is the general trend in each line?	What are the trends in each row? What are the trends in each column?
relational	Relating items in list	How are different lines related to each other? How are lines on related graphs related to each other?	Which rows are related? Which columns are related? How are blocks of data related?
extended abstract (contextual)	Integrating ideas into disciplinary concepts	What scientific models does this data draw on? What other variables does this data suggest should be investigated? How might the methodology have affected these results?	What scientific models does this data draw on? What other variables does this data suggest should be investigated? How might the methodology have affected these results?

widely used to classify the thinking processes of individuals by stages and substages (Ashton, 1975; Shayer and Adey, 1981). This change in emphasis from a classification of behaviours, to a classification of individuals, can lead to theoretical and practical problems. Not the least of these is the 'problem' of explaining how an individual can perform in the manner expected at one stage in one context, and in a manner expected of another stage in another context. As has been pointed out by DeRibaupierre *et al.* (1991), this is not a weakness of the theory, but an implication of it. The objections do not negate the benefits of establishing the presence of specific Piagetian abilities to examine performance in particular situations, but suggest the tantalizing possibility that performance and competence might be improved by developing these abilities.

The SOLO taxonomy of Biggs and Collis (1982) is designed mainly as a means to classify the quality of responses (rather than students) in a variety of disciplines; from creative writing to mathematics. The categorization recognizes levels of response that correspond to substages of Piagetian development (Biggs and Collis, 1982). It can also be visualised as a spiral learning structure, repeating itself with increasing levels of abstraction, making it suitable as a diagnostic tool throughout primary, secondary, and tertiary education (Biggs and Telfer, 1987). The SOLO taxonomy proposes four stages: unistructural, multistructural, relational, and extended abstract. The main features of each stage are as follows (Collis and Biggs, 1979; Biggs and Collis, 1982; Collis and Davey, 1986; Biggs and Telfer, 1987):

Work characterised as **unistructural:**
- uses a single relevant piece or aspect of the available information;
- makes generalisations on the basis of this one aspect;
- may display premature closure because all available data has not been utilised.

Work characterised as **multistructural:**
- uses several pieces of relevant information, but does not relate them to each other;
- makes generalisations based on a few aspects independently of each other;
- shows a feel for consistency, but can reach inconsistent answers by focusing on separate aspects of the data;
- can show an understanding of 'one group with, and one without' in experimental design.

Work characterised as **relational:**
- considers data as a whole with a coherent structure and meaning;
- uses and inter-relates all available information;
- induces general conclusions from the available data only;
- seeks consistency within the data, but does not draw on data beyond the system under consideration;
- searches for control of obvious variables;
- can make use of simple quantitative algorithms such as $s = ut + ½at^2$.

Work classified as **extended abstract** (or contextual):
- uses and inter-relates all available information, and tests it against appropriate abstract constructs suggested by the data;
- uses deductive logic to relate specific data to general rules;
- generalises about hypothetical situations;
- can recognise alternative approaches and use combinatorial reasoning, resulting in a willingness to leave conclusions open;
- can extend structures under consideration to take in new and more abstract features;
- searches for ways to control possible variables, and looks for interactions between variables.

The initial and current use of the SOLO taxonomy has been primarily diagnostic, focusing on the work rather than its author, where 'responses from particular content areas were looking for a way of assessing learning outcomes, and these are only partly dependent upon the developmental levels of individuals.' (Collis and Biggs, 1979). While this approach has allowed us to use a valid and reliable means of assessment in various disciplines (Biggs and Collis, 1982), the authors remind us:

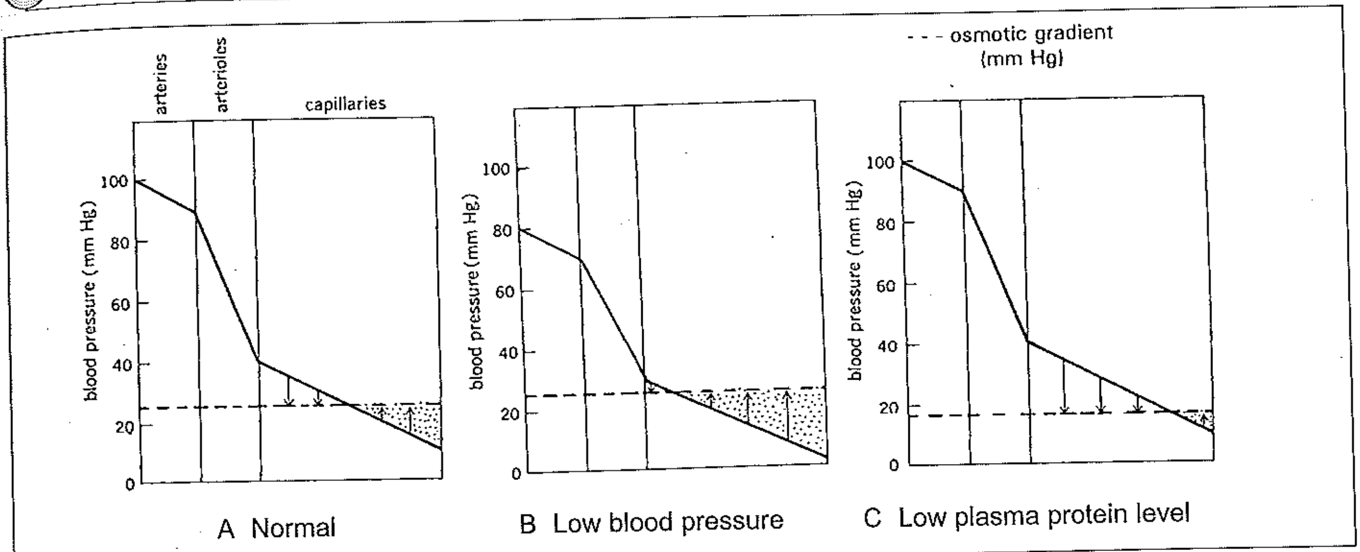

Figure 1 *Formation of tissue fluid from plasma in different situations, (reproduced from Yip, 1998)*

Introducing the graph

Topic
- From the graph title, what is the general topic being examined? (one phrase answer)
A... *fluid movement ...*
- What is the accompanying text (if available) trying to suggest?
A... *fluid filters out from and in to capillaries ...*

Scope
- From the graph title and the footers, what do all the groups being studied have in common?
A... *tissue fluid formation ...*
- From the graph title and the footers, which groups are not included in the study?
A... *high blood pressure, high plasma protein*

Comparisons made
- From the labels on the graph lines, what is the difference between the groups being studied?
A... *different disease conditions*
- From the labels on the vertical axis, how are the groups being compared?
A... *blood pressure*
- From the labels on the horizontal axis, how are the groups being compared?
A... *location in circulatory system (arteries/arterioles/capillaries)*

Reliability
- From the footer information (and text if available), what evidence is there that this information is reliable?
[Not applicable]

Definitions
- In this graph, what is the meaning of the following word(s)?
Blood pressure
A... *pressure transmitted from heart contractions squeezing water out of blood vessels.*
Osmotic gradient
A... *pressure difference sucking water into blood vessels caused by different concentrations of chemicals inside and outside the vessels.*

Figure 2 *Typical questions for a graph and answers relevant to Figure 1 to move students to unistructural thought.*
Note. While the questions are relevant to most complex graph sets, not all are suited to all occasions. The answers in square brackets are of less importance for the example from Yip, 1998 in Figure 1. This convention has been used throughout the paper.

'Whether or not this model may result in the generation of strategies of intervention remains at this stage an intriguing possibility'.

A potential obstacle has been the genetic determinism attributed to Piaget's work (Chapman, 1988). However, evidence has accumulated in recent years to suggest that the performance of subjects can be enhanced in two ways. First, it is possible to arrange the testing situation so that the individual can display his or her abilities to the best advantage. Not only can students perform better when questions are set in a culturally relevant context (Cole and Scribner, 1974), but it is possible for students to display rapid progress as a result of increased test readiness (Bovet, 1974). Secondly, and more interestingly, two groups have demonstrated lasting, improved competence following interventions that teach active, analytical methods (Shayer and Adey 1992 a,b, 1993; Lawson and Snitgen, 1982; Lawson, 1985).

Since the SOLO taxonomy is based on the analysis of material presented, rather than the individual presenting the material, it has the potential to be used as a powerful teaching tool. Making clear the expectations and mechanisms for interpreting relevant numerical material, and providing opportunities for developing these skills, appears to foster the learning environment recommended by Shayer and Lawson's research. This paper outlines an adaptation of the SOLO taxonomy that provides students, and their teachers, with a pedagogically sound template which can be used to develop critical numeracy skills in the biological sciences.

Using SOLO to teach critical numeracy in graphs and tables

A robust teaching methodology must provide students with the mechanisms for interpreting commonly encountered graphs and tables. The most ubiquitous and problematic type of graph has sev-

Introducing the table

Topic

- From the table title, what is the general topic being examined? (one phrase answer)

A...*cats predating wildlife*

- What is the accompanying text (if available) trying to suggest?

A...*bells may have an effect on the predation level*

Scope

- From the table title and the footers, what do all the groups being studied have in common?

A...*all are cats*

- From the table title and the footers, which groups are not included in the study?

A...[not applicable]

Comparisons made

- From the labels on the top row, how are the groups being compared?

A... *Different prey animals from cats with and without bells*

- From the labels on the left-hand column, how are the groups being compared?

A... *Degree of urbanization*

Reliability

- From the footer information (and text if available), what evidence is there that this information is reliable?

A... [not applicable]

Definitions

- In this table, what is the meaning of the following word(s)? Proportion?

A... *The number of cats that killed the animals divided by the total number of cats*

***Figure 3** Typical questions and answers for a table to move students to unistructural thought. The answers in square brackets are of less importance for Table 2.*

eral treatment groups. Similarly, complex tables with multiple sub-groupings seem to pose the greatest challenge for students. The following discussion develops a stage-specific template (Table 1) to improve critical analysis of a graph and a table selected from recent editions of the *Journal of Biological Education* (Figure 1, from Yip, 1998; Table 2, from Calver *et al.*, 1998). These were selected because they contain the more complex features of their types, (for example comparing multiple groups and subgroups), and would be considered a challenge for any teaching strategy. In Figures 2 and 3, the bold lettering highlights the general types of questions that a teacher can use to encourage understanding using the SOLO-based technique.

Table 2 Proportions of cats with and without bells, which killed birds, mammals, and reptiles in three different localites (Paton, 1991).

Locality	*Birds*		*Mammals*		*Reptiles*	
	With bell	*No bell*	*With bell*	*No bell*	*With bell*	*No bell*
Suburbs	0.62	0.59	0.60	0.58	0.20	0.25
Country towns	0.55	0.72	0.58	0.61	0.58	0.40
Rural	0.25	0.54	0.56	0.58	0.38	0.38
Total	0.47	0.62	0.58	0.59	0.39	0.34

This table is reproduced from Calver *et al.*, 1998.

This pattern can be used by teachers to produce their own questions for other stimulus materials, in the way that the bullet-pointed questions do for the selected graph and table. The answers provided are typical of student responses demonstrating achievement at that level.

Starting analysis

Meaningful analysis begins when the student recognizes the relevant framework for the graph or table. The important pointers that establish the context of the data must be understood before the student can produce critically numerate responses. This is the first point of departure between a mathematical and a critical numeracy. In mathematics, the substance of the data is held within an equation. In the biological sciences, the essence lies within the factors surrounding the measurement. Thus, it is important for the student to explicitly examine the circumstances behind the data. Methods to increase the effectiveness of this preliminary analysis have been dealt with in a number of different approaches (for example, Marshall, 1997). While important as orientation exercises, these do not provide a developmental pattern to help students to acquire a better understanding in the way described below.

Unistructural competence: point analysis

Like the Piagetian epistemology, Biggs and Collis' SOLO taxonomy describes responses which focus on a single aspect of the data in unistructural work. In these cases the material under examination draws on one relevant, usually prominent feature from the question to the exclusion of other available material, resulting in premature closure. Teachers will be familiar with students who respond to all questions when analyzing a graph, with an answer giving the highest (or lowest) point on the graph. Given the natural drawing power of such features, they provide a useful place to begin an analysis.

At this level, teachers should encourage students to identify the most notable data points. This is not a problem for the majority of students, as the skills involved are not only rudimentary, but form a common link between mathematical and critical numeracy. As these skills are normally well established in mathematics, students are able to transfer them easily. For example, there is little difference in noting the use of turning-points for determining the equation of a parabola in mathematics, and recognizing the analogous point when determining enzyme efficiency in biology. Indeed, a problem I frequently observe in secondary and tertiary biology is the tendency to extrapolate uncritically from data, just as is appropriate in mathematics. In biology exceptional values are often critical. These can be outliers or data that are inconsistent with currently held theoretical stances, and do not normally arise in non-probabilistic mathematics. While both require attention, it is this latter group that students are prone to overlook.

When examining a graph or table, the template attracts the student's attention to notable values that limit the range. Where raw data are used it may also be necessary to draw the student's attention to outliers and any extraordinary values. Some sample questions for the graph and table in Figure 1 and Table 2 are shown in Figures 4 and 5 respectively.

What are the most important points in the graphs?
Range and Limits
- What is the highest and lowest blood pressure in the capillaries in:

a) Normal individuals A... *40 mm and 10 mm*
b) Low blood pressure A... *30 mm and 5 mm*
c) Low plasma protein A... *40 mm and 10 mm*

- What is the highest and lowest pressure of the osmotic gradient in:

a) Normal individuals A... *25 mm and 25 mm*
b) Low blood pressure A... *25 mm and 25 mm*
c) Low plasma protein A... *15 mm and 15 mm*

Figure 4 Typical unistructural questions and answers for the data in Figure 1. General areas for questioning that form the template are shown in bold lettering. Dot points show typical questions for the example, with typical responses demonstrating achievement at that level. This convention is used thoughout the paper

What are the most important points in the table?
Range and Limits
- What type of cats from which locality are the most prevalent killers of:

a) birds A... *country cats with no bell (0.72)*
b) mammals A... *country cats with no bell (0.61)*
c) reptiles A... *country town cats with a bell (0.58)*

- What types of cats from which locality are the least prevalent killers of:

a) birds A... *rural cats with a bell (0.25)*
b) mammals A... *rural cats with a bell (0.61)*
c) reptiles A... *suburban cats with a bell (0.58)*

Figure 5. Typical unistructural questions and answers for the data in Table 2.

Multistructural competence: trend analysis

Piaget noted how a child becomes capable of integrating a series of successive states of an object into a transformation. Within the SOLO taxonomy this ability is associated with multistructural responses. At this level, the work under examination shows evidence of taking several points into consideration, albeit rather list-like in form, without forming relationships between items in the list. Thus, the student recognizes trends within individual sets of data, but may not relate the sets of data to each other. There are several important goals that students must reach to master this level of development.

First, the student should be starting to generalize the data from the classes in the numerical text provided, by looking for consistency within the class of data points. As with point analysis, the skills required are similar to those required for mathematical numeracy. However, the overriding concern in mathematics for quantitative precision can be a distracter when dealing with critical numeracy, where the qualitative nature of the change is often sufficient. In direct contrast to mathematical numeracy, it would therefore seem appropriate initially to concentrate on the qualitative analysis, and then move to the quantitative analysis. In doing so, the student is given the opportunity to manipulate the classes within the data prior to arranging them into meta-classes in the relational step which follows. Thus the worksheet should allow the student to compare the important datum points located during the point analysis with their 'surrounding' data, first qualitatively, and then quantitatively if required. To move the student into trend analysis, the worksheet that accompanies the graph might use questions such as those in Figures 6 (for a graph) and 7 (for a table).

What are the most important trends in the graphs?
- What happens to the blood pressure as it flows through the capillaries?

A... *It decreases*
- What happens to the osmotic gradient as blood flows through the capillaries?

A... *It stays the same*

Figure 6. Typical multistructural questions and answers for the data in Figure 1.

What are the most important trends in the table?
Within blocks
- Compare adjacent rows to answer this question. How many instances are there where at least 5 % less cats with bells prey on animals than cats without bells for:

a) birds A... *2 (country towns and rural cats)*
b) mammals A... *0*
c) reptiles A... *1 (suburban cats)*

Between blocks
- Look at the bottom row to answer this question. (Note: These are really averages rather than totals.) Does the data suggest that cats wearing bells eat less wildlife than cats without bells?

A... *No, fewer eat birds, but about the same number eat mammals and more of them eat reptiles.*

Figure 7 Typical multistructural questions and answers for the data in Table 2.

Relational competence

The most important feature of the relational stage is that the student should be able to inter-relate the information from different sections within the numerical text. As might be expected from a model of this type, the analysis required of students builds from the products of the unistructural and multistructural analyses, where the attention of the student was drawn first to critical points, and then to the flow between them. Responses that can be classified as relational '[integrate] the parts with each other so that the whole has a coherent structure and meaning' (Biggs and Telfer, 1978).

During relational analysis of graphs and tables the student is asked to compare the flows in one data-set with the flows in the other data-sets in order to establish patterns of co-variation (as a necessary condition to establish causality), or divergence between data-classes. In the case of the graph, this would usually mean drawing together the different lines of the graph, or in the table, different rows and columns. To promote relational analysis, the worksheet that accompanies the graph might use questions such as those in Figures 8 (for a graph) and 9 (for a table).

Extended abstract competence: message analysis

The relational analyses need to be distinguished from higher-level inter-relationships that are the basis of many statistical analyses. This is the relationship between the observed data and that which might be expected by chance. This association is

What are the most important relationships in the graphs?

Between lines in one graph

- How does the relationship between blood pressure and osmotic gradient change as you move through the capillaries?

A...*blood pressure is greater near the arterioles and less at the end (near the venules)*

- Where does water flow from the capillaries into the tissues?

A... *At the venule end of the capillary bed.*

- Where does water flow from the tissues into the capillaries?

A... *At the venule end of the capillary bed.*

Between relationships in one graph

- Look at the sections of the graphs relating to circulation in the capillaries. Compare the proportion where capillary blood pressure exceeds osmotic gradient (shown by arrows pointing down to the osmotic gradient line) in each graph, and the proportion where osmotic gradient exceeds capillary blood pressure (shown by arrows pointing up towards the osmotic gradient line). Compare the area of these two sections:

a) In the 'normal' graph A... *they are about the same*

b) In the 'low blood pressure graph' A... *capillary pressure lower has the largest area*

c) In the 'low plasma protein' graph' A... *osmotic gradient lower has the largest area*

Between related graphs

- In which graph is the area where blood pressure exceeds osmotic gradient the greatest?

A... *The low plasma protein graph*

- In which graph is the area where osmotic gradient exceeds capillary blood pressure the greatest?

A... *The low plasma protein graph*

Figure 8 *Typical relational questions and answers for the data in Figure 1.*

data relate to higher-order, abstract, theoretical structures. The learner searches for alternative explanations through uncontrolled variables, and can pose hypothetical situations, which test the findings.

To demonstrate critical numeracy in the sciences, particularly at undergraduate level, the student is required to interpret data in the context of prevailing theory. This means that the student must extend the understanding of the relationships within the data, to the relationships between the data and abstract concepts. To do so, the student must be able to evaluate the relevance and applicability of diverse ideas within the discipline, and select appropriate abstractions for that context.

Frequently, the critical numeracy component of a unit will involve the student in producing propositions, which must be tested against the data. The ability to work with propositional logic is associated with formal thought (Bond, 1987). In many respects the conditional proposition 'if ... then ... else...' is a restatement of the classical hypothesis-null hypothesis statements which underlie much of empirical science. As such, symbolic propositions are an essential feature of a critical approach to science.

quite distinct from those within the empirical data, since it rests on the relationships between the data and its conformance to some abstract theoretical position, so therefore properly belongs at the level of message analysis.

An extended abstract answer is distinguishable by the generalization of 'the structure to take in new and more abstract features, representing a higher mode of operation' (Biggs and Telfer, 1987). The responses may show lack of closure, with students retaining an open mind with regard to alternative conclusions. Inparticular, responses show an appreciation of how the

At higher levels students may also be required to evaluate the probable validity and reliability of the data on the basis of the methodology used. This extends the student's understanding of relationships within the data, to recognize the impact of experimental design, the limits of measurement, and the uncertainty in the conclusions reached. Problems in this area display themself when students extrapolate data without considering the effects of variation, probability, or uncontrolled variables.

To provide a support to move students towards message analysis, the worksheet that accompanies the graph might use questions such as those in Figures 10 (for a graph) and 11 (for a table).

What are the most important relationships in the table?

Between vertical blocks (types of prey)

- Look across the rows to answer these questions. How does the predation rate for each type of animal differ?

(a) Reptiles

A...*Lowest (although there is higher predation in country towns by cats with bells)*

(b) Mammals

A... *Consistently high*

c) Birds

A...*Moderate (although relatively low for 'belled' cats in rural areas)*

Between horizontal blocks (degree of 'urbanness')

- Look down the columns to answer this question. Under what circumstances is decreasing 'urbanness' *consistently* correlated with changes in predation rates, and what is the trend in each case.

A... *Birds get preyed on less by cats with bells, and Mammals might get preyed on less by cats with bells*

Figure 9 *Typical multistructural questions and answers for the data in Table 2.*

Conclusion

The author has used this adaptation of the SOLO taxonomy over 3 years for 1st year tertiary education and biological science students, and found it to be a useful and reliable tool to develop critical numeracy. The template structure allows teachers to formulate questions for almost any graph or table, and focuses the students' attention on to a specific set of features at

What is the meaning of the graph?

Theories

- What is the net flow of water where capillary blood pressure in the capillaries is:

(a) greater than the osmotic gradient?

A...*Water flows from the capillaries to the tissue fluid.*

(b) less than the osmotic gradient?

A...*Water flows from the tissue fluid into the capillaries.*

Propositions

- What would you expect to happen in the tissue of a person with:

(a) low plasma protein level? A... It would swell up (become oedematous).

(b) low blood pressure? A... It would become dehydrated.

- What would you expect to happen in the tissue of a person with a protein deficiency who undertakes vigorous exercise? Justify your answer in terms of the osmotic gradient and the capillary blood pressure.

A... *The low plasma proteins would result in a lower osmotic gradient and a higher blood pressure would be associated with a higher capillary blood pressure. The result would be that capillary pressure forcing fluid from the capillary would exceed osmotic gradient forcing fluid into the capillary throughout the length of the capillary network making the swelling worse.*

- Kwasiokor is a form of malnutrition often seen in young children during famines. An obvious symptom of this disease in the children is their swollen abdomens. Explain how they can have swollen abdomens despite their starvation.

A... *These children lack protein in their diet and this would be reflected in low plasma protein levels. Consequently the balance between capillary blood pressure and the reduced osmotic gradient would occur at the arteriolar end of the capillary network with a net gain of fluid in the tissues.*

Methodology in context

Variation

- The graphs are theoretical and are not taken from a real person. Would you expect this to happen in real situations? How might these results be different in real patients?

A... *for example, they may not show straight lines and each individual would be different.*

- What do you think might be some practical problems in measuring blood pressure in different parts of the capillary bed?

A... *for example, (1) determining how far the individual capillary is from the nearest arteriole and venule; or (2) finding a pressure sensor that would fit into the capillary without affecting the pressure being measured.*

Figure 10 Typical extended abstract questions and answers for the data in Figure 1.

each stage of development. The questioning sequence described uses Biggs' SOLO taxonomy to combine well-researched Piagetian theory with Shayer and Lawson's proven methodologies. In this way the teacher can not only promote a better understanding of specific biological concepts, but also provide students with a useful tool to develop their underlying scientific competency and critical numeracy.

References

Ashton, P.T. (1975) Cross-cultural Piagetian research: An experimental objective. *Harvard Educational Review*, **45**, 475–505.

Beveridge, W.I.B. (1950) *The art of scientific investigation*. New York, USA: Random House.

Biggs, J.B. and Collis, K.F. (1982) *Evaluating the quality of learning: the SOLO taxonomy*. New York, USA: Academic Press.

Biggs, J.B. and Telfer, R. (1987) *The process of learning* (2nd ed.). Hobart, USA: Prentice-Hall.

Bond, T.G. (1987) An investigation of the scaling of Piagetian formal operations. In *Adolescent development and school science*, eds. Adey, P., *et al*. pp.334–341. New York, USA: Falmer.

Bovet, M.C. (1974) Cognitive processes among illiterate children and adults. In *Culture and cognition*, eds. Berry, J.W. and Dasen, P.R. pp. 311–334. London: Methuen.

Calver, M.C., King, D.R., Risbey, D.A., Short, J., and Twigg, L.E. (1998) Ecological blunders and conservation: the impact of introduced foxes and cats on Australian native fauna. *Journal of Biological Education*, **32**, 67–72.

Chapman, M. (1988) *Constructive evolution*. Cambridge: Cambridge University Press.

Cole, M. and Scribner, S. (1974) *Culture and thought*. New York, USA: Wiley.

Collis, K.F. and Biggs, J.B. (1979) *Classroom examples of cognitive development phenomena: the SOLO taxonomy*. Hobart, USA: University of Tasmania.

Collis, K.F. and Davey, H.A. (1986) A technique for evaluating skills in high school science. *Journal of Research in Science Teaching*, **25**, 651–663.

DeRibaupierre, A., Rieben, L., and Lautrey, J. (1991) Developmental change and individual differences: a longitudinal study using Piagetian tasks. *Genetic Social and General Psychology Monographs*, **117**, 285–311.

Flavell, J.H. (1962) *The developmental psychology of Jean Piaget*. ed. vanNostrand, D. NJ, USA: Princeton.

Goodnow, J.J. (1980) Everyday concepts of intelligence and its development. In *Studies in cross-cultural psychology*, ed. Warren, N. Vol 2., pp.191–219. London: Academic Press.

Halloun, I.A. and Hestenes, D. (1985) Common sense concepts about motion. *American Journal of Physics*, **53**, 1056–1065

Lake, D.C. (1996) *Quantitative approaches to the Piagetian analysis of temporal concepts held by Papua New Guinean trainee teachers*. Ph.D. Thesis: James Cook University, Townsville.

Lawson, A. (1985) A review of research on formal reasoning and science teaching. *Journal of Research in Science Teaching*, **22**, 569–617.

Lawson, A. and Snitgen, D.A. (1982) Teaching formal reasoning in a college biology course for preservice teachers. *Journal of Research in Science Teaching*, **19**, 233–248.

Marshall, L. (1997) *A learning companion* 2nd ed. Perth, WA, USA: Murdoch University.

O'Connor, M. (1991) *Writing successfully in science*. London: Chapman Hall.

What is the meaning of the table?

Theories

- On the basis of this data, can you say whether predation by cats is an important factor for wildlife management?

A... *The proportion of cats reported to predate wildlife is very high, however we have limited information in a number of important areas. In particular, we would need to know the total number of cats, the total number of each form of wildlife, the number of kills per cat in a given period, and the reproduction rate of each form of wildlife.*

- Is 'belling' cats an effective way to reduce predation?

A...*The data would suggest that there is not a large difference between 'belled' and 'unbelled' cats in the degree of predation for most wildlife. The exception would be for birds in rural districts and country towns where 'belling' does seem to have some beneficial effect.*

Propositions

- Explain why 'belling' might be effective in some circumstances but not in others?

A...*It may be that birds are more sensitive to sound than either mammals or reptiles. Support for this proposition would come from the extensive use of sound by birds in alarm, territorial, and mating displays, a use not found as widely in mammals or reptiles. The 'belling' may be more effective in rural areas and country towns where there are fewer competing noises, particularly bell-like noises.*

Methodology in context

- How much variation would be required between related data (e.g. between 'belled' and 'unbelled' cats in a particular location for a particular prey type) for you to accept a real difference between them.

A... *[This question would lead into a discussion about the need for statistical methods to determine central tendency, spread and sampling techniques which would be taken further in the next question]*

- What additional information might you require to be more confident in drawing conclusions from the data?

A... *for example, (1) the sample size for each group; (2) how each respondent gauged evidence for predation (predation by farm animals may go unnoticed, and the predation of small lizards is less evident than predation of birds or mammals); and (3) the degree of predation for individual animals (a farm 'mouser' may take native fauna on a daily basis as a primary dietary source, where a suburban house-pet may predate only occasionally).*

Figure 11 *Typical extended abstract questions and answers for the data in Table 2.*

Reynolds, L. and Simmonds, D. (1981) *Presentation of data in science.* Dordrecht: Martinus Nijhoff.

Shayer, M. (1972) Conceptual demands of the Nuffield O-level physics course. *School Science Review*, 54, 26–34.

Shayer, M. (1974) Conceptual demands of the Nuffield O-level biology course. *School Science Review*, 56, 447–458.

Shayer, M. (1978) Nuffield combined science: do the pupils understand it? School *Science Review*, 60, 210–233.

Shayer, M. and Adey, P.S. (1981) *Towards a science of science teaching.* London: Heinemann.

Shayer, M. and Adey, P.S. (1992a) Accelerating the development of formal thinking in middle and high school students II: Post-project effects on science achievement. *Journal of Research in Science Teaching*, 29, 81–92

Shayer, M. and Adey, P.S. (1992b) Accelerating the development of formal thinking in middle and high school students III: Testing the permanency of effects. *Journal of Research in Science Teaching*, 29,1101–1115

Shayer, M. and Adey, P.S. (1993) Accelerating the development of formal thinking in middle and high school students IV: 3 years after a 2 year intervention. *Journal of Research in Science Teaching*, 30, 351–366

Singer, C. (1959) A short history of scientific ideas to 1900. London: Oxford University Press.

Weissberg, R. and Buker, S. (1990) Writing up research. Englewood Cliffs, N. J., USA: Prentice-Hall.

Yip, D.Y. (1998) Teachers' misconceptions of the circulatory system. *Journal of Biological Education*, 32, 207-215.

Dr David Lake is a Lecturer in Science Education at Murdoch University, School of Education, Murdoch, Western Australia 6150. Tel: +61 8 9360 2484; fax. +61 8 9310 8780; e-mail: dlake@cleo.murdoch.edu.au