Using questions to promote active learning in lectures

Communication

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The first key to wisdom is constant questioning...
By doubting we are led to enquiry, and by enquiry we discern the truth.

Peter Abelard (1079-1142)

An attempt has been made to remedy some of the deficiencies of the traditional didactic lecture by enhancing student involvement and learning through the use of focussed questioning within the lecture format. The potential benefits of questioning are considered and the effectiveness of the approach is evaluated through classroom observations, peer observation, an end of module questionnaire and student discussions. Some limitations of the approach are identified and suggestions for future improvements are made. The paper concludes with a brief consideration of the importance of thinking time to the promotion of meaningful learning.

Introduction

30 years ago when I started teaching I believed that I had knowledge to impart and that the better I taught the more my students would learn. When I, like many others,[1] came to realise that what my students were learning was not always what I was trying to teach them, I tried to teach better. What I then found, however, was that the better I taught the better my teaching was rated by students but not, alas, the better they learned. It was only when I encountered *constructivism*[2, 3, 4] and Alex Johnstone's *Information Processing Model of Learning* (Figure 1)[5, 6] that I started to think about the learner and realised that I needed to teach not just better but differently. Knowledge, alas, can't simply be transferred from the teacher to the learner, much though we might wish that it were otherwise, but meaning must be constructed in the mind of the learner.[2] I see an analogy with digestion where even for a cannibal, ingested proteins are not incorporated directly into body structures but rather are broken down before being reassembled into useful biomolecules. Learning involves the linking and interpretation of incoming information with what is already known by an individual. As we all have different stores of knowledge in our long-term memories (Figure 1) we may all interpret incoming information differently.

If we look into the black box between teaching and learning it seems reasonable that where new information can be satisfactorily linked to pre-existing knowledge and interpreted this will be likely to happen. Piaget[2, 7] referred to this process as *assimilation* and under low resolution it is indistinguishable from simple information transfer. However, this will not always be the case, particularly throughout the education process; confusion

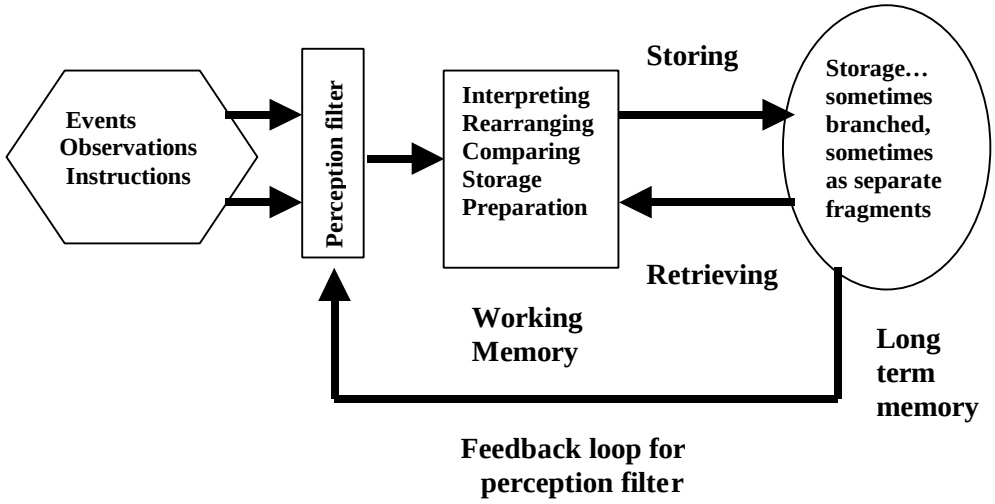

Figure 1. Information processing model for learning

(disequilibrium) will occur whenever new information can't readily be assimilated into existing schemes. What happens now? Such input can simply be ignored, and it is my belief that this is exactly what our students are increasingly choosing to do, it can be linked and interpreted incorrectly leading to so called alterative frameworks[8] or the learner may resort to rote memorisation and try to save the information without linking it to existing knowledge. None of these, of course, represents an acceptable learning outcome from the perspective of the teacher. The possibility also exists however, that the learner will modify the pre-existing schemes until any discrepancies can be resolved. Piaget referred to this process of modifying and developing pre-existing schemes as *accommodation*.[2,7] Education surely involves learning not just more but better and I believe that the promotion and facilitation of accommodation is of pivotal importance in this.[9] The better we organise information and link it to what we already know, the more easily it is likely to be recalled and applied to new situations in the future. However, Herron recently postulated that learning operates on a principle of minimum effort.[10] This suggests that whenever possible the learner will resist restructuring cognitive schemes, preferring to ignore data that don't fit, or to make false connections. Only when the learner becomes really dissatisfied with existing structure will modification start to occur. One can go so far as to suggest that a bad lecture, whatever that may be, followed by peer group discussion or outside reading represents a much richer learning experience than a good lecture, whatever that may be, with minimum student follow-up. Anything which produces active involvement of the learner is therefore likely to enhance the quantity and in particular the quality of learning.

Research by Anderson in 1980 found that questions interspersed in text were amongst the most effective aids to help understanding.[11] I therefore decided to use focussed questioning to try to promote learning within a lecture format. The aim of questioning was not to assess current knowledge or understanding; though undoubtedly some misconceptions, which need to be rectified quickly, will be identified. Rather, the questions sought to promote active learning through the stimulation of thinking and the creation of disequilibrium. Questions can contribute positively in at least four ways:

(a) They may promote both variety in the presentation and more active student involvement during lectures.
(b) They may stimulate learning by relating new information to knowledge already stored in long-term memory (Figure 1).
(c) They may help to identify what is particularly important to concentrate on, *i.e.* they may 'tune the filter' (Figure 1).
(d) They may indicate to the learner where further width or depth of knowledge is needed and help stimulate thought by generating disequilibrium in the learner's mind. Over the years many unsuccessful students have told me that they had expected to do much better in my examinations than they did and that they had understood the material when I covered it in my lectures.[12] They hadn't of course, but like passengers in a car who see no problems with the journey because the driver knows the way, they are incapable of retracing the journey on their own at some future date. It therefore seemed particularly important to break through this complacency.

A question that contributes positively in any of these ways can be considered successful, but I was particularly interested in promoting learning through forcing students to reassess their current knowledge and understanding by creating dissatisfaction with current thinking.

The Study

A 12 week, one hour a week sequence of lectures on bioinorganic chemistry was used to evaluate this approach. The lectures, supported by 12 hours of associated laboratory time, represented one third of a final year honours degree module. The module was taken by 36 full-time students on the BSc (Hons) Applied Biochemical Sciences degree and by 10 part-time students studying for Chemistry or Life Sciences degrees. All students had previously studied some biochemistry as well as chemistry modules, all were well known to me and all but three had been taught by me previously. I started the course with a brief introduction to my ideas about how meaningful learning can take place and to metacognition.[13] The importance of active engagement with new information and participation in class activities was stressed. This occupied about 20 minutes at the start of the first lecture. It was gratifying to note subsequently, that during informal discussion with several students in individual studies advice sessions, students both understood and appeared to support the approach being taken.

Each lecture commenced with a brief synopsis of what was to be covered and one *Big Question* that would be developed and considered during the course of the lecture. The aim of these questions was to prompt students to think about a key problem. Examples of such questions included: *Why are only certain elements used by life?* and *How are ion gradients produced and maintained in the body?* A significant number of questions, about ten each lecture, were also posed during the lectures. These were either targeted at individuals or the class as a whole but were to be answered directly. Research has clearly identified that waiting time must be adequate if questioning in the classroom is to be productive.[14] Care was therefore taken to ensure that adequate time was available and multiple contributions from the class were encouraged. Examples of questions used included: *(1) What is a Lewis acid? (2) Given the solubility product of* $Fe(OH)_3$ *as* 10^{-38} *what is the maximum concentration of free* Fe^{3+} *available in aqueous media at pH7?* and *(3) If copper is the catalytic site what is the likely role of zinc in superoxide dismutase?*

While the first of these questions does appear to require only simple factual recall, its purpose is not to find out that most students on hearing the word acid immediately think of hydrogen ions. Rather it is used to alert the individual that knowledge in long-term memory (Figure 1), which relates to polarisation will be needed. Lewis acidity is a major and recurring theme on the course and related questions used in subsequent lectures included: *Why are metal ions needed when the proton is so effective as a polarising cation? When would 'life' choose to use* Mg^{2+} *rather than* Zn^{2+} *as a Lewis acid catalyst?* and *Why do you think 'life' chooses* Zn^{2+} *rather than* Cu^{2+} *as a Lewis acid catalyst?*

Question 2 is more complex, requiring both conceptual understanding and a 'back of the envelope' calculation. Given time most students should have been able to solve this problem, but in the lecture context progress was only made after some prompting on how best to proceed. In many ways the final question might be considered the most demanding of the three. Here some students had little difficulty in deciding that the most likely role would be structural. Although this question predated any detailed discussion of the biological roles of zinc, a general consideration of roles undertaken by metal ions had previously taken place.

In their own way each of these three very different questions can be thought to show that what is being presented is more complex than it might at first appear and hence create a learning opportunity.

Four approaches were used to evaluate the effectiveness of the approach just described:

(a) Classroom observations.
(b) Peer observation in week 10.
(c) An end of module questionnaire.
(d) A group discussion with three students (four were invited but one was unable to attend) conducted in week 10.

Results

(a) ***Classroom Observations***

Having explained the importance of active participation at the onset, I had hoped that willingness to contribute would improve rapidly once students became familiar with the process. However, while five or six students were regularly prepared to contribute, the vast majority avoided answering unless directly challenged. The lullaby effect[15] was apparent with many answers being shallow and not indicative of deep thinking. For example, to the question *"Why is lead not an essential element?"* the answer *"because it is toxic"* seemed to be accepted by all the students. Only after I pointed out that oxygen had been extremely toxic to the earliest forms of life did the class appear to be willing to refocus on cause and effect. Although the level of student contributions fell below what I had hoped for, perhaps it was unreasonable to expect to obtain evidence of meaningful learning concurrent with the teaching (*vide infra*). As an optimist, I can still hope that the stimulus/disequilibrium resulting from the questions may still initiate active engagement with the information over a more appropriate time scale.

(b) ***Peer Observation***

As it was the process rather than the content that was of interest, I decided against using a fellow chemist and asked the Coordinator of Learning and Teaching for the Faculty of Business and Management if she would sit in and observe one of my teaching sessions. We met some 15 minutes prior to the lecture and I briefed her on what I was trying to achieve in the session; she made a series of notes throughout the lecture and we met up for a debriefing session later on the same day. Although much good practice was identified, the key observation as far as I was concerned was that I eventually answered all the questions myself. The students knew that I was going to do this and were happy to wait for my answers.

(c) ***Student Questionnaire***

The questionnaire asked students to assess the helpfulness of six aspects of the teaching on a six-point scale and then invited free responses relating to the best aspects of the teaching, the worst aspects of the teaching and any suggestions as to how teaching might be improved. The questionnaire was handed out at the end of the last lecture. One student was asked to collect and return the completed questionnaires to me; 34 were subsequently returned. The questionnaire and responses to the six Likert-scale questions are shown in the Appendix.

All six aspects of the teaching, which were evaluated, appeared to be well supported by the class with a significant majority assigning one of the two top grades for each feature. The course booklet, which contained gaps (many of which related to the questioning) to be filled in during the lecture, received outstanding ratings from students returning the questionnaire. They were familiar with the use of structured incomplete handouts as I use this approach throughout my teaching.[16]

Although no textbook was recommended, students were informed that any modern inorganic text was likely to contain a relevant chapter well worth reading. 16 references to original papers were provided and the lecture to which each related, was indicated. Five complete compilations of the 16 references were made available to the class to be used and shared throughout the semester. Several students chose to make their own copies. My discussion on how learning takes place was also generally well received and, as noted above, discussion with students led me to believe that they both understood and supported the ideas outlined.

The usefulness of both the *Big Question* and *frequent questioning* appeared to be highly rated. Hopefully

this suggests that even where students were reluctant to voice their opinions they were still thinking about the questions. The free response questions (7, 8 and 9) did provide some interesting information. All respondents identified a best aspect of the teaching. A clear majority (19 students) identified the course booklet, which is primarily a simple information transfer technique, as the best aspect of the teaching. Only four students out of 34 returned questionnaires opted for the questioning. Few students listed any worst aspects though two suggested that there was a lot of material to cover and this led to things being rushed. A further two suggested that starting the lecture at 9.15 on Monday mornings was the worst aspect. Only the following suggestions for improvement were made:

(i) More marks for coursework.

(ii) Review answers to past examination papers to enable students to know what will be required.

(iii) Supplement references with appropriate web page addresses.

While these suggestions all seem reasonable, (i) and (ii) provide further evidence for the assessment-driven motivation for learning which we continue to encounter[17] and (iii) would be more justified if there was evidence that the 16 references provided had been well studied.

(d) ***Group Discussion***

A number of issues, mirroring the questionnaire, which I wanted discussed were considered by three of the students. I was there introducing the topics but I took no part in the discussion. The students talked about each issue for some minutes and one student wrote a summary of the consensus view. The group considered that the discussion on learning was a good way to start the course and was useful because it prompted students to think about how they learned. The students thought that the introduction of frequent questions during lectures was beneficial because it helped them to realise how well, or how little, they understood the topics being discussed. The *Big Questions* were also considered useful because they helped to unify each lecture. It was, however, suggested that more active discussion of these questions would help.

Reflective Discussion

Though the approach appeared to attract widespread student support, it clearly did not produce the increased levels of student participation that I had hoped for. It is tempting to suggest that the assessment-driven motivation which directs the behaviour of most students probably means that they did not want to answer my questions, they merely wanted to know my answers. However, perhaps on reflection, my aims were rather ambitious. A majority of students appear likely, initially, to resist any innovative approach to teaching,[18] so an attempt to introduce the questioning approach was unlikely to meet instant success. Clearly, however, if progress is to be made students must be coerced into contributing more effort towards developing their own answers and hence, enhancing their knowledge creation. Unfortunately it seems likely, as recently suggested by Bahor *et. al.*[19] that learning does not occur simultaneously with but after the teaching. This suggests that more success might be encountered if students were required to answer the questions at some time in the future. I have in fact tried to finish lectures with a question, which the class will be required to answer at the start of the next lecture but it was evident that only a few students thought about these questions in the meantime. I believe that I have had success with the use of buzz groups[12] but this is a very time demanding process and thus has to be used sparingly. A recent paper by Hutchinson[20] suggests that awarding some marks for participation will encourage interaction. However, I suspect that Hutchinson's success can probably be attributed to the fact that their students are required to study appropriate chapters before coming to the classes. As this approach was common throughout the general chemistry teaching programme, the students appeared comfortable with the requirements and complied with them. My use of questioning, however, differed from what students encountered in other lectures and more familiarity with the approach is probably needed before progress could be expected. Any attempt to promote more interactive learning will not be straightforward and, unless innovations are introduced with care, may even be counterproductive. I recently heard of a Management module in the third year of an engineering degree where the lecturer asked students to prepare information for oral presentation to the next class. The next class was attended by only 11 of the 110 enrolled students.

The use of student questionnaires for both teaching quality assessments and the evaluation of teaching innovations is now widespread. The present study supports my own experiences over many years that these questionnaires need to be interpreted with caution, particularly the quantitative aspects. I believe that many unwarranted conclusions continue to be drawn from the indiscriminate use of such data.

Peer observation was employed as an assessment tool almost as an afterthought, yet this clearly provided an extremely useful insight into what was actually happening. Perhaps I should have seen what was happening, perhaps I eventually would have; it was certainly clear once the suggestion was made. The experience certainly convinced me that we could all benefit from sympathetic and constructive peer observation and support.

Throughout the course there was constant conflict between time required for questioning and the demands of the curriculum. I can only agree with the two students who suggested that the course was rushed in parts. It seems certain that increased student interaction will require more time than simple didactic teaching. It is therefore perhaps

instructive to consider the importance of time to learning.

Some Thoughts on the Relevance of Time to the Learning Process

It is clear from earlier comments that meaningful learning requires effort and is therefore likely also to require time. However, the information-processing model (Figure 1) which has been so useful to understanding how we learn, is, at least in the way that I have viewed it, a time independent model. Yet time is clearly a key variable in determining the quality of learning that can take place. It is surely much easier and therefore quicker merely to transfer information to the learner than for meaningful learning to occur. In fact I suggest that getting the information into the mind of the learner is really the first step towards meaningful learning. This corresponds to what is usually called rote memorising or surface learning. Time and effort are then required to link, interpret, possibly correct (if initially misconstrued) and then accommodate this new information to produce deep or meaningful learning. So, far from being alternatives, rote memorising and meaningful learning may be considered as different stages within the learning process (Figure 2). The second step requires both effort from the learner and time for meaningful learning to develop. The model is clearly consistent with recent suggestions that teaching less, *i.e.* reducing the rate of information transfer, can actually lead to more learning taking place.[21, 22, 23, 24] The model thus predicts that where new concepts are being taught, sufficient time as well as effort is required to enhance cognitive schemes through accommodation, and therefore questions the pedagogical soundness of the recent move towards wide-spread semesterisation in UK universities. Students all too often treat each module as an isolated unit and do not have, or do not take, the time to reflect on what they memorised. It would indeed be tragic if current benchmarking exercises served to increase curricula rather than to embrace and scaffold learning outcomes.

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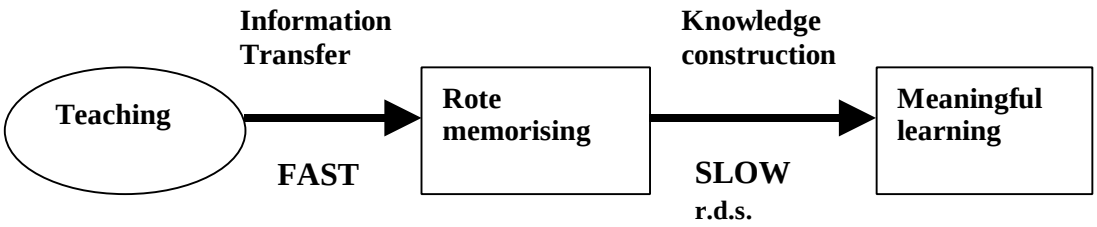

Figure 2 . Model showing the time dependence of learning

Appendix

Bioinorganic Chemistry

Student Opinions on Teaching Approach

Please indicate by ticking appropriate box how helpful you have found each of the following features of the teaching *(stating with 0 to indicate useless rising to 5 where you would consider the feature indispensable).*

	0	**1**	**2**	**3**	**4**	**5**
1. Course booklet					9	25
2. Recommended references		1	5	10	11	7
3. Discussion on how learning takes place		2	3	10	13	4
4. Big question		1	1	13	13	6
5. Frequent questions during lectures			1	10	15	8
6. Prelab session		4	4	6	13	3

Number of responses for each option were as shown above

7. Please indicate what you consider to be the best aspects of the teaching.

8. Please indicate what you consider to be the worst aspects of the teaching.

9. Please indicate how you believe the teaching could be improved for you.

References

1 C.J. Garratt, *U.Chem.Ed.*,1997, **1,** 19
2 G.M. Bodner, *J.Chem.Ed.*, 1986, **63,** 873.
3 L.B. Resnick, *Science*, 1983, **220,** 477.
4 .N. Spencer, *J.Chem.Ed.*, 1999, **76,** 566.
5 A.H. Johnstone, *J.Chem.Ed.*, 1997, **74** 262.
6 A.H. Johnstone, *Educ.Chem.*, 1999, **36**, 45.
7 R. Good, E.K. Mellon and R.A. Kromhout, *J.Chem.Ed*., 1978, **55,** 688.
8 K.S. Taber, *Educ.Chem.*, 1999, **36**, 135.
9 G.J.Posner, K.A. Strike, P.W. Hewson and W.A. Gertzog, *Science Education* 1982, **66,** 211.
10 D. Herron, *The Chemistry Classroom: Formulas for successful teaching*, American Chemical Society, Washington, DC, 1996, p.18.
11 D. Herron, *The Chemistry Classroom: Formulas for successful teaching*, American Chemical Society Washington, DC, 1996, p.21.
12 W. Byers, Don't Throw the Baby out with the Bathwater, *Proceedings of the 4th European Conference on Research in Chemical Education*, Univ. of York, 1997 p.52.
13 D. Rickey, and A.M. Stacy, *J.Chem.Ed.*, 2000, **77,** 915.
14 M.B. Rowe, *J.Res.Sci.Teach.*, 1974, **11,** 81.
15 M.L. Bigge and S. Shermis, *Learning Theories for Teachers, 6th Ed*., Longman, New York, London, 1999, p.285.
16 W. Byers, *Proceedings of Variety in Chemistry Teaching 1995*, ed.-s J. Garratt and T. Overton, Royal Society of Chemistry, London.
17 A.H. Johnstone, *Educ.Chem*., 2000, **37,** 12.
18 R.F. Orzechowski, *J.Col.Sci.Teach.*, 1995, 347.
19 M. Bahar, A.H. Johnstone and R.G. Sutcliffe, *J.Biol.Ed.*, 1999, **33,** 134.
20 J.S. Hutchinson, *U.Chem.Ed.*, 2000, **4,** 1.
21 F. Garafalo and V. Lo Presti, *J.Chem.Ed.*, 1993, **70,** 353.
22 C.J. Garratt, *U.Chem.Ed.*, 1998, **2,** 29.
23 A.B. Arons, *J.Col.Sci.Teach.*, 1980, **10,** 81.
24 A.H. Johnstone and W.Y.Su, *Educ.Chem.*, 1994, **31**, 75.