Developing students' thinking skills in science

Patricia Outen
Hitchin Girls' School, Hertfordshire

Abstract
Patricia Outen graduated from the Herts MEd in Leading Teaching and Learning in 2006. In this article, she describes how she and a fellow science teacher worked with students preparing for their GCSE examinations to develop their cognitive abilities and understanding in science.

Students often say that science subjects are difficult. My project began with me wondering why this might be the case and how science teachers might help their students develop their understanding (Outen, 2006). It has become increasingly apparent that students need to understand principles rather than to rely on learning by rote. In other words, students need to 'know how' as well as 'know what' (National Curriculum on Line, 2000). Although memorising facts may give students a feeling of confidence or even safety, this strategy may only be the cognitive equivalent of colouring in a diagram. Learning a strategy that allows them to solve one problem does not guarantee success with a similar one, only with an identical one. Students need to understand rather than just repeat, which demands something more of both students and teachers. In my experience, younger students seem to be more effective learners: they seem more involved in lessons, eager to question, more confident and relaxed when challenged by the experience of making mistakes. By contrast, older students often appear more passive and reticent. There are many reasons why this might be the case - puberty for example - but there is clearly a need for teachers to help and encourage students to maintain their active approach in science lessons. I therefore wanted to explore how we could teach in a way that serves the best interests of our students.

Twenty First Century Science

My school has piloted the 'Twenty First Century Science' double award course at GCSE level. 'Twenty First Century Science' grew from the recommendations of the report, 'Beyond 2000' (Millar and

Osborne, 1998), which identified the failings of science curricula at that time. However, teaching this new science course demands different and more varied skills from teachers. I therefore had a golden opportunity to modify my practice, re-assessing how to teach science in the light of a new specification. GCSE students are now required to know how to question, to be able to discuss issues and to draw conclusions. I therefore wanted to work with my colleagues in the science department, helping them to encourage our students to develop their cognitive skills as required by our new curriculum.

My starting point was finding out the extent to which my own students could identify their difficulties in science. I decided to carry out a series of semi-structured interviews with three articulate Year 11 students. Although these students were regarded as high achievers in school, they often expressed worries and concerns about their understanding in physics lessons. The interviews yielded three main points about student involvement in lessons and in their own learning. Firstly students acknowledged a tendency to be passive in lessons, although one student felt that questioning was the method by which she gained understanding. Secondly students agreed that it was more difficult for them to deal with concepts and the application of knowledge. Thirdly there was an acknowledgement of the need for greater reflection.

Two comments offered by these students appeared particularly perceptive to me.

> *When we talked about it, more and more came back. Doing it made me understand. I can see it now.*
>
> (Helen, Year 11)

This last statement referred to students working collaboratively to produce a summary of their learning during a lesson. By working in a group, students had found it easier to deal with demanding concepts and higher level thinking. However when the discussion turned to how students' thinking can be used to promote understanding, the following statement gave me a key insight into how I could plan a series of lessons to develop thinking skills.

> *Yeah, if you're told, then you need to understand it. The 'how', 'when', 'why' is the understanding.*
>
> (Nicola, Year 11)

This acknowledged the need for questioning to pursue understanding. This might be questioning of students by the teacher, questioning of the teacher by the students or questioning of students by each other.

I wanted to confirm that the three themes I had identified were relevant to other students. During a subsequent discussion with a group of three middle-ability Year 10 students, the same problems were identified. They also attached a great deal of importance to the teacher ensuring that students were engaged in an activity that promoted their learning and saw questioning as an effective method of achieving this. Furthermore, these students associated passivity in class with a tendency for behaviour to deteriorate. They recognised that when the whole class was actively contributing to the lesson, better learning was the result.

> *I learn much more in physics because each lesson we have the ....., uum,..... interactive whiteboard and it just explains everything, and you learn it so much better and everybody is in a class discussion and everybody is involved in the lesson and you just learn so much, and it's fun.*
>
> (Millie, Year 10)

There were themes that related to both the structure of our teaching and the effectiveness of student learning. These were cognitive conflict, construction and metacognition. Interestingly, there seemed to be clear parallels between these insights and those which had prompted the CASE (Cognitive Acceleration through Science Education) programme (Adey, 1999) used with students as they started at secondary school.

I have summarised these links in the following table:

Problem identified	**Course of action**	**Link with CASE**
Student passiveness	Student involvement through tasks which involve collaborative working	Cognitive conflict – students respond to cognitive challenge by working with peers or teacher
Using higher order thinking e.g. considering concepts	Socratic questioning (pupil-teacher or pupil-pupil)	Students work in their Construction Zone, developing the reasoning through questioning

Reflection on learning	Teacher encourages students to reflect on their learning and to summarise it	Metacognition – students consider how they solved problems, who helped them to do so, where difficulties lay, what reasoning they used

I saw the teacher's role as that of a facilitator, prompting students' thinking when required. I also wanted to encourage a collaborative atmosphere to encourage students to develop their understanding more fully. Whilst the teacher would be part of this collaboration, she should also provide opportunities for cognitive conflict as well as reflection.

Keeping a 'Learning and Understanding Log'

The Year 10 specification of the 'Science for the Twenty First Century' course aims to develop students' opinions by promoting discussion of relevant scientific issues. Therefore, the style of the course seemed to lend itself well to the purposeful use of Socratic questioning as detailed by Paul (1993). I particularly wanted to use questions that would encourage students to clarify their views, probe their assumptions and challenge their thinking regarding reasons and evidence. It was my intention that students should engage in this activity whilst working collaboratively. I decided that it would be helpful for both me and my students if some of their thoughts were recorded in a lesson-by-lesson 'Learning and Understanding Log'. I felt I would then be able to plot the progress of the intervention by indicating the level of student reflection, collaborative working and understanding. I also hoped that it would help my students to maintain their focus.

I identified a series of lessons in which I could use an activity drawn from a physics module entitled 'Radiation and Life'. This deals with a range of ideas and concepts that requires students to make judgements about how science and technology affects them now and in the future. This was therefore an ideal area to allow for discussion, questioning and reflection. My co-worker, Alison Salmon, identified a biology topic, 'Health Matters' which gave students the same opportunities for discussion, reflection and questioning. Both Alison and I were able to work with our middle ability Year 10 students.

Alison and I both used this activity in several lessons over the course of a term. We started each lesson by introducing the area of study and explaining the lesson objectives. This equates to what CASE terms 'concrete preparation' but it is also standard classroom practice for many teachers. Students were then encouraged to complete the tasks as set out, prompted by written questions. This gave students the opportunity to work collaboratively for the majority of the lesson. We generally observed that they stayed on task well and seemed engaged in discussions prompted initially by the questions. As Chin (2004) remarks, question-asking can facilitate knowledge construction. Questions can 'stimulate students to generate explanations for things which puzzle them and to propose solutions to problems' (Chin, 2004:107). If, as suggested, this resulted in students using deep-thinking strategies then cognitive abilities would have been exercised. This process lasted over a time span of approximately forty minutes; each lesson is one hour long in total. If a group of students appeared to be losing concentration, we redirected their thoughts by asking a question. The lesson then drew to a close with a class discussion of the ideas met which led students to reflect on and summarise their learning in the 'Learning and Understanding Log'.

Collaborative working: One section of the log provided evidence of what students found difficult in the lesson and who helped them most with their understanding. I wanted to see if there was a shift over time in students' focus from the teacher or the text book to that of other students within the class.

Reflection: The log contained a series of questions inviting students to question, wonder or comment on their learning during the lesson. Again I wanted to probe whether students became more likely to respond positively, showing an increased capacity for reflection as time progressed.

Understanding: It is difficult to assess lasting understanding but I was more interested in students' perceptions regarding their understanding. The students' responses to whether the objectives of the lesson had been met and understood, together with their final summaries of their learning, were used as indicators of understanding.

Insights from the logs

Reading the logs gave me an insight into how our students were approaching and developing their learning. I looked for trends regarding the extent to which students felt positive about their understanding, and how helpful and collaborative the process had been.

The level of understanding reported by students was consistently high throughout the intervention. I looked for clear statements from students that they had understood the material; the students' summary of their work acted as verification of understanding. Interestingly, the lowest level of understanding was recorded in one of Alison's lessons. This was concerned with the reliability of news stories and required students to read contemporary accounts of scientific topics (particularly in the field of biology), discuss them, question their accuracy and evaluate them. Whereas most of the students considered this to be a straightforward and interesting exercise, a significant minority reported difficulties in understanding.

> *The evidence to back up an article was hard to find and establish. I still don't understand it'.*
>
> (Jenny, Year 10)

Whilst students may not have regarded this as traditional lesson content, it is very much in keeping with the aims of our new specification. Alison prompted student thinking throughout the lesson by her use of questioning. Whether the students retained their understanding is a different matter, and one that relates to whether they had perceived themselves as having gained a deep understanding or merely a surface understanding. Prosser and Trignell (1999) regard a deep approach to learning as being characterised by students aiming to understand ideas and seeking meaning. An indicator of developing understanding might be the observed degree of purposeful discussion undertaken by students.

As each intervention lesson had contained an element of collaborative working, I was interested to see if students identified this as being helpful in aiding their understanding. Specific references in the student logs suggested that discussion with friends was the prime method by which understanding was achieved. Both Alison and I were confident that our students had generally engaged purposefully when working collaboratively. A high degree of

participation was felt to be important as studies indicate that high achievers tend to be more actively engaged in class, whilst more off task behaviour is observed from low achievers (Burns and Myhill, 2004). However, I was surprised by the student response to my question about the impact of collaboration. The proportion of my students who identified collaborative working as being of major significance stayed fairly low, only fluctuating between 25% and 36%. I had initially expected that, as students became more adept at working with each other, they would have viewed this as an increasingly rewarding exercise. However, more light was shed by the trends revealed by the students' comments. Initially, these showed a high dependence on the teacher for explanations. As time progressed, more rewarding interactions between students were described and skilful practitioners within the classroom community were identified. The teacher was also seen increasingly as a consultant in the search for understanding rather than a source of information. In other words, the students were becoming more active in their own learning. I witnessed many pupils' dialogues moving from simple exchanges of information to a learning process whereby knowledge was constructed in a 'collaborative community' (Wells, 1999). This process was also coupled with more students naming the variety of methods they were employing to build their understanding. They become more adept at taking responsibility for their learning and seemed more active in seeking understanding.

Finally I was interested in seeing how much students were able to continue the reflection beyond the confines of the particular lesson. In one of my preliminary interviews with Year 11 students they talked about hurtling from lesson to lesson without any reflection on their learning. When I designed the log I wanted to find out whether students could carry the reflection with them. The logs did provide some evidence of metacognition and indicated a general trend in the right direction. This is exemplified by part of Sarah's reflection at the end of a lesson on global warming:

> *It is important to remember about global warming and greenhouse gases. A question I have is, how long can the Earth go on like this?*
>
> (Sarah)

Comments often showed evidence of higher-order thinking as the students explored 'knowing how' by speculating and planning. Similarly, summaries of learning generally evolved from a simple

sentence indicating limited use of knowledge to more detailed and varied methods such as mind maps.

Final student interviews helped to confirm my understanding. I was struck by how closely linked collaborative working, student reflection and teacher input were in the minds of my interviewees. Whilst I had tended to regard them as separate entities, my students interwove them in their discussions, describing their effectiveness in aiding understanding. Students acknowledged that collaborative working had been helpful in aiding understanding. They liked working with others with whom they felt comfortable so that they did not feel diminished by acknowledging difficulties. Careful teacher intervention was also seen as being vital when students 'got stuck'. It was clear that a prompt in the form of a hint or a question was regarded as being useful whereas understanding was not developed if teachers simply supplied the answer to problems.

> *Giving us the answers or whatever is a bit, like, just giving us nothing to do. It's not a challenge.*
>
> (Rachel)

Conclusions

Alison and I judged that we had become more effective in our use of questioning through this project. By modelling questioning, we noticed that our students were able to ask deeper, more pertinent questions which explored their understanding more fully. We felt that this area of the intervention had the most impact on us as teachers.

We also believed that students' understanding was enhanced as they learnt to reflect successfully on their learning. Many students demonstrated increased confidence when talking about their thinking about how they learn. Furthermore, like others before us, we observed that our students developed a greater ability to take control of their learning and to work independently (Conner, 2004).

The project itself impacted not only on our teaching but also contributed to the debate on teaching and learning within our science department, and throughout the school, as we shared accounts of our work with the rest of the staff. We continue to question, to encourage collaborative working and reflection to promote better understanding. No doubt, students still feel that developing

understanding requires effort, but as teachers we now have a clearer view as to how to facilitate this process.

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