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12. Choice for the gifted: lessons from teaching about scientific explanations

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This Chapter explores the potential value of 'choice' as a feature of science teaching planned for the most able in science classes. Student choice is one feature of learner-centred approaches to teaching (see Chapter 5). The context of the Chapter is a sequence of activities focused on the notion of 'scientific explanation'. The approach taken is considered to offer a number of features that link to the needs of the most able science learners. In particular, there were a number of ways that the lesson activities offered 'choice', and positive student responses to the sessions seemed linked to this notion. It is suggested here that choice, as a principle to inform lesson planning, relates to a number of the issues that are considered important in teaching the gifted:

- Creativity: by providing open-ended activities (Stepanek, 1999);
- Differentiation: by allowing students to respond at different levels (NDE, 1997);
- Engagement: by offering opportunities to link to personal interests (Renzulli, 2004);

- Metacognition: by requiring pupils to make judgements e.g. about which examples to tackle, and when to move on to another example (Shore & Dover, 2004);
- Task demand: by offering opportunities for higher level cognition (VanTassel–Baska, 1998).

The activities discussed here were developed for use as curriculum enrichment for 13-14 year olds, so the particular teaching sequence did not have to fit within a fixed scheme of work. None-the-less, the general principle exemplified here can certainly be a consideration in planning more regular teaching.

The science context: the nature of scientific explanations

As discussed elsewhere in this volume (in particular, see Chapters 2 and 14), the nature of science is considered to be (a) a key focus for a science education that prepares young people for adult life in technologically advanced democracies; (b) an area where student understanding has often been found to be very limited; and (c) a potentially fruitful source of ideas and activities to engage and challenge the most able students.

Explanation would seem to be central to the essence of science. A naïve view might claim that science *discovers* knowledge about the World, although it might be more accurate to suggest that science *creates* knowledge through the development of theories. The theories are used in turn to understand, predict and sometimes control the world, and in these activities, scientific explanations play the key role. We might consider theories and models to be the resources of science, but explanations to be the active processes through which theory is applied to contexts of interest (Gilbert, Taber & Watts, 2001). In science itself, as in an individual's science learning, the conceptual and the cognitive are complementary and interlinked.

An explanation is an answer to a 'why' question: but that in itself neither makes for a good explanation, nor for a scientific one. There is no simple answer to what does count as a good explanation, in science or elsewhere. Explanations have audiences, and to some extent, a good explanation is one that satisfied its audience – in other words it meets the explainee's purpose in seeking an explanation. Additionally, it has been known since at least Aristotle's time that we can talk of different kinds of causes, which suggests that many 'why questions' might have different *types* of acceptable responses, depending on the type of cause being sought.

For the purposes of the teaching episode considered here, pupils were told that scientific explanations needed to take into account *logic* and *theory*, i.e. that *the explanation needs to be rational, and the explanation needs to draw upon accepted scientific ideas*. As the notion of 'theory' is itself known to be difficult for students, they were also told that *scientific theories are ideas about the world which are well supported by evidence; are internally consistent; and which usually fit with other accepted theories*.

The teaching context: working with a top set with a wide ability range

The work discussed here was undertaken with a Year 9 (i.e. 13-14 year old) top science set in a maintained (state funded) 11-16 comprehensive school in the City of Cambridge, England. The school has a very cosmopolitan intake, and tends to have higher than average numbers of students who are considered to be able, as well as high numbers of those needing various kinds of learning support. Due to timetable organization, the year group was split into two parallel half-years, and so the ability range within a top set is quite wide – i.e. including the most able, but covering something like the top quartile of the attainment range.

The author visited the school late in the school year (when most of the pupils would be 14 years old), to work with the group over two 50 minute periods, either side of the lunch break. There were 28 students present for the sessions: nine girls and 19 boys. At this point in the year the group had completed the prescribed science curriculum for 11-14 year olds, and time was made available for enrichment activities. The sessions consisted of a sequence of activities on 'explanations' in science, designed to build-up to an activity where students would be asked to evaluate a set of 'explanations' as poor or good scientific explanations, and to justify this by reporting their criteria for the judgments. The general outline of the teaching sequence was:

- Introduction to the ‘teacher’ (KST) and the theme of the sessions;
- Suggest an explanation: a warm-up activity to remind pupils that producing satisfactory explanations is far from trivial, and to introduce the notion of an explanation being a response to a ‘why’ question;
- A teacher-led presentation on the theme of scientific explanations;
- Explanations wanted: pupils were asked ‘what are the questions you would most like to know the answers to?’;
- Sequencing explanations: selecting, sequencing, and connecting components of explanations;
- Evaluating explanations: selecting examples of poor and good scientific explanations, and justifying choices;
- a short questionnaire to find out what, if anything, the pupils enjoyed and/or found challenging about the work.
- In addition, two pairs of students (a pair of boys, a pair of girls), selected by the normal class teacher as able students who would be happy to talk, were interviewed.

In this Chapter I will explain the nature of the lesson activities, and consider some examples of student responses. It is important to note that the ‘teacher’, being a visitor to the school, did not know the pupils, and did not know which of these top set learners were considered ‘gifted’. However, a key feature of the approach used was to provide activities that had the potential to stretch the most able, whilst still allowing other pupils to fully engage and respond at their own levels. Whilst such ‘differentiation by outcome’ was pragmatically necessary in the particular context of these lessons, such an approach is also consistent with the views expressed elsewhere in this volume (e.g. see Chapters 1 and 2), i.e. that whilst it is important to ensure the most able learners are stretched, it is less desirable to apply labels that encourage us to limit our expectations about which students have the potential to demonstrate gifted traits in our classes.

Student responses to the teaching episode.

Suggest an explanation:

The first activity was intended to introduce the notion of an explanation being a response to a 'why' question. It was thought important that this activity should meet three criteria: be potentially challenging for the most able; be something that all the students could successfully engage with; and it should connect to student interests. A large bank of 'why' questions were prepared (fifty in total). Students were asked to work in pairs, and copies of the set of questions were distributed around the room so that students would be able to select a few questions that interested them.

Students became quite engaged in this activity, and it was allowed to run on whilst they remained on task and seemed to be enjoying the challenge. One of the most noticeable features of the set of responses was the extent to which answers were produced which were coherent, often extended, and matching scientific explanations. Although some of the questions should have been familiar from school science, this was still striking. That said, there were also a number of dubious suggestions, and many of the suggested explanations would be considered incomplete. However, the examples in Table 12.1 represent some of the more accomplished responses. Although it is clear that some of the examples involved reproducing previously taught material, they none-the-less suggest that these ideas have been learnt with sufficient understanding to allow pupils to construct credit-worthy explanations.

When the pupils were asked at the end of the teaching episode which activities they found challenging, the most popular suggestion was this set of questions. Nine students suggested this as a challenging activity, and at least one of the students had identified something pretty fundamental about the nature of providing explanations: 'if you get an answer you can always ask why again and you can never explain it all'. In contrast, previous work has suggested that many students soon reach a point where they accept 'that's just how it is' (Watts & Taber, 1996).

The pair of girls interviewed had appreciated the chance to select which of the questions they should attempt to answer, choosing biology examples which they judged easier. They still found the activity challenging, as they had to 'go over' it, starting with 'a basic idea, but then you think further into it'. One of boys interviewed described the activity as 'quite interesting because it definitely makes you think because…it's quite specific, so you're sort of making yourself think, with other knowledge'.

Table 12.1: Examples of explanations provided by 13-14 year olds

Presentation:

The students were then given a presentation on the theme of scientific explanations. To get across the idea that scientific explanation can be quite complex, two examples were considered: the size of the known universe and natural selection. The different types of evidence that collectively support a Darwinian explanation of the evolution of modern life forms were reviewed (the 'explanation' to the question 'why do we believe life has evolved'?) The cosmic distance ladder was used as the second example – an explanation for how we have come to be able to put a value on the distance to the farthest detectable objects.

These two areas of scientific theory gave a glimpse of how scientific explanations can sometimes depend upon chains of logical connections (and so on a significant number of potentially incorrect assumptions), or may sometimes be based upon a weight of circumstantial evidence where definitive proof is not logically possible. These scientific 'stories' – one from the life sciences, one from the physical sciences - were thought to be suitable to interest the more able student – as well as giving an excuse to project images of dinosaurs and stars!

Explanations wanted:

The students were then set a task to think about over their lunch break – 'what are the questions you would most like to know the answers to'? After the break the students were each given a sheet headed. 'Explanations wanted (The questions I'd most like to know the answers to)', and asked to suggest their own questions. Many of the suggestions related to biology (e.g. '*Why* do we have an appendix apart from to get appendicitis?'), especially human biology (e.g. '*Why* do men have nipples?'), or behavioural science (e.g. '*Why* are some things instinctive and others you have to learn?'). Although there was some interest in 'cosmic' questions (e.g. '*Why* have we found no other life in space?'), there were relatively few questions relating to the physical sciences (e.g. '*Why* do cornflakes go soggy?') among the group.

Quite a few of the questions should be answered at some point during school science (e.g. 'Why do we get bruises?'; 'Why do humans take so long to grow up to adults compared to other animals?'), but there were also quite a few perceptive questions that were likely to remain a mystery in terms of the normal school curriculum (e.g. 'Why do humans have emotions?'; 'Why do some people have perfect pitch?'; 'Why do dogs wag their tails when they are happy?')

Elsewhere in this volume, Mike Watts and Helena Pedrosa de Jesus discuss the value of using students' questions in teaching the most able learners. Many of the questions elicited from this group of 14-year olds would either form a useful starting point for science that is in the curriculum, or could provide the basis of interesting enrichment work.

Sequencing explanations:

The next activity concerned sequencing potential components of explanations. This task was intended to build upon the earlier presentation where the complex (i.e. branching, or daisy-chained) nature of explanations was considered. The activity was introduced on an overhead projector, using the question 'why do solid substances melt when they are heated?' A set of statements, including some false ones, were moved around the projector glass to form a possible structure for a valid scientific explanation of the level expected in the school curriculum.

The students were then provided with a choice of two examples to work on in small groups. They were given information about the task:

> 'At the top of the sheet you will find a question. The statements on the sheet may help you construct an explanation to answer the question. However, you may not need all of the statements, and some may have been included to confuse you!'

The students were also given a set of instructions to cut out the statements, rearrange them on a large sheet of paper, and then stick them down adding suitable connecting words ('because' etc.) and any additional information they wished to include.

The groups were given a free choice between a life science example ('Why do plants die if kept in the dark'), and a physical science example ('Why is it important to use renewable power sources?'). These were expected to be questions that students would already have some ideas about, so the focus of the task was thinking about *how to structure* the explanation rather than working out what the answer could be. Both examples included some irrelevant or false statements, but these were included less to catch students out than to reduce any expectation that there was a single correct response comprising of a particular arrangement of all the statements.

Only one group completed the 'energy resource' option, producing an explanation that can be represented (with *italics* used to show words added by the students):

> It is important to use renewable power sources:
>
> *Because* burning fossil fuels contributes to the greenhouse effect; *And* if the greenhouse effect becomes more intense then the average global temperature may increase.
>
> *Because* burning fossil fuels releases sulfur dioxide into the air; *And* sulphur dioxide is converted to sulphur trioxide in the air; *And* sulphur trioxide dissolves in water to make sulphuric acid.
>
> *Because* at the rate we are using fossils fuels we are likely to exhaust the supply within a century; *Because* fossil fuels take millions of years to form

This group were then able to sequence an explanation with three separate 'threads' or aspects - the greenhouse effect, the production of acid rain, and the disparate timescales for the production and use of fossil fuels. Each of the threads is relevant and logically constructed.

Most groups chose to work on the question about plants, and responses of varying levels of complexity were produced. So the following example discarded most of the material provided, giving a simple, but logical explanation.

> Plants die if kept in the dark:
>
> *because* plants produce their food by photosynthesis; *and* photosynthesis requires energy; *and* plants use the Sun's light as the energy source for photosynthesis

Other groups tended to produce longer, and more involved explanations. These commonly included some flaws in the logic of the explanations, suggesting this task was genuinely challenging their thinking. The following example demonstrates a flaw found among the suggestions of several groups:

> Plants die if kept in the dark:
>
> *because* plants produce their food by photosynthesis; *and* photosynthesis requires energy; plants use the Sun's light as the energy source for photosynthesis; *therefore* plants contain a substance called chlorophyll which allows them to use the Sun's light as a source of energy; *and* photosynthesis is a chemical process where carbon dioxide and water are reacted to form sugar (glucose) and oxygen

In this example a good start is made of producing a logical chain, but the last two statements do not sit well in the sequence. This was quite typical of responses, in that the students seemed to be trying to include material that they saw as relevant, but had difficulty fitting it into the chain of explanation. Even when groups used the approach of having several threads of argument (as in the argument for renewable energy sources, above), they still found it difficult to formulate chains of argument. For example,

> Plants die if kept in the dark
>
> *because* plants use the Sun’s light as the energy source for photosynthesis; *and* plants produce their food by photosynthesis; *because* photosynthesis is a chemical process where carbon dioxide and water are reacted to form sugar (glucose) and oxygen; *and* photosynthesis requires energy
>
> *and* plants contain a substance called chlorophyll which allows them to use the Sun’s light as a source of energy; *because* photosynthesis requires energy

This argument contains logical steps, but also material not directly relevant to the argument being made. A tentative suggestion is that these students had (rote) learnt that certain scientific facts were central to questions about this topic (the chemical reaction; the significance of chlorophyll) and felt the need to include these facts in a ‘good’ answer, even when it was not immediately clear how they fitted. Teaching argumentation in school science has only recently become the focus of teacher preparation (e.g. Erduran, 2006), and is probably not currently an explicit focus of much science teaching.

When asked what they found challenging, five of the pupils cited the sequencing activity. Activities that involve cutting-and-sticking may still involve considerable cognitive demands – in this case ‘deciding if something was relevant in the flow charts’. This may be worth bearing in mind as some pupils clearly enjoy these – as one student put it - ‘kinetic activities’.

The interviewed girls again appreciated having some choice in the sequencing activity – ‘it would be more difficult it you had done the one you didn’t want to do, but if you do the one you want to do it’s obviously because you might have some idea of what to do’. They clearly found the deliberate provision of redundant information made the task more complex, and added to the challenge – although this could be irksome:

> ‘It was good, but it was a bit annoying having all the things that weren’t relevant to it as well, cause you had to, *I suppose it was good really because you had to think about it*, which are relevant, but it was quite, annoying really, having to sort them out, and there were the ones that you knew were true, but they weren’t relevant so you couldn’t put those in as well’ [emphasis added]

The boys who were interviewed described this activity as ‘pretty good, it was quite interactive as well’. They reported that,

> ‘it makes you think, cause you’re reading it and you’re sorting it out yourself…you still had to think which ones were right and which ones weren’t relevant, so yeah it did involve a bit of thinking’.

Evaluating explanations

The final task concerned ‘critiquing explanations’. Students were provided with a set of 35 explanations, and asked to select examples of good or poor scientific explanations. The set was designed to include explanations of various degrees of complexity, including some with a range of flaws and weaknesses. Again working in groups, students were provided with two A3 sheets on which to glue their chosen examples. One sheet was headed ‘poor scientific explanations’ and had a series of boxes for students to complete the statement ‘This is a poor explanation because...’. The other sheet, headed, ‘good scientific explanations’ had a single box to be completed: ‘A good scientific explanation...’

The groups were asked to identify the characteristics they used to select good scientific explanations, and they were able to identify a number of pertinent criteria, e.g.:

> *A good scientific explanation…* is where the question is answered thoroughly. The answer doesn’t repeat itself and it gives a detail[ed] description of the answer. The explanation explains the subject in detail, and makes it very clear so the reader can understand it easily.
>
> *A good scientific explanation…*doesn’t ignore other possibilities. It is logical, and the answer is relevant. It doesn’t leave any questions unanswered. It should not assume that things are connected.
>
> *A good scientific explanation…*does not go around in circles it is clear and concise complies with recognised scientific ideas. It is essential it is logical. It includes few complex words and sentences.
>
> *A good scientific explanation…*is rational and logical and has a solid grounding in accepted scientific theories.

The responses suggested that groups included logical argument, relevance to the questions, consistency with accepted scientific ideas, and clarity for the audience as relevant criteria. These were ideas that had been alluded to in the presentation, but it was still reassuring to see that students had taken up and could apply these points.

Perhaps of more interest was the selection of poor scientific explanations, as here there was the potential for applying criteria to identify when an explanation fell short. Weaknesses of some examples were readily identified:

e.g. Bacteria cause disease because they are tiny single-celled living things.

> it doesn't explain why being a tiny single-celled living thing causes disease
>
> The facts are correct but the explanation is unclear
>
> There are lots of single-celled living things which don't cause disease – the statements are not connected

Other examples were more readily analysed by some groups than others. For example one explanation offered was that '*Acids are dangerous, and when using hydrochloric acid you should always wear safety spectacles. The stomach produces hydrochloric acid to digest food, so you should always wear safety spectacles when digesting food.*' Whilst some groups selecting this as an example of a poor explanation were able to give appropriate reasons (e.g. '*they make the assumption that the acid is of the same strength. The acid is nowhere near the eyes', and 'When you are using acid externally you wear glasses, but when it is internal you should not'*), other groups offered weaker justifications: '*Is not a sensible explanation. Does not make sense'*. As with the sequencing task, critiquing explanations seemed to both engage the students' interest, and provide a genuinely challenging activity for the range of abilities in this top set.

Four members of the group suggested this activity was challenging. The girls interviewed found that this activity 'was harder than the first ones', apparently because it involved two different types of criteria, relating to logical coherence and scientific veracity. One of the girls observed that something that had the form of a good explanation might be based on weak premises 'if you don't know that much about what you're talking about, then you might think it's a good explanation but it could just be like a simple version that you understand', and her companion observed that 'a good explanation doesn't have to be true'.

These girls felt they did not have the background to judge some of the explanations put before them, but this did not cause a problem as 'there were quite a lot of them, so you could choose, the ones you weren't sure you could just leave out, and there were enough to do it with the other ones as well'. One of the boys interviewed suggested that as 'there were more options, that made you think more'.

Overall response to the sequence of activities.

At the end of the session, students were asked *what (if anything) did you enjoy about* the lessons. There were a wide variety of responses to this question, with some citing particular activities, while others suggested features of the sessions. Five students referred to how the sessions allowed them to use their own theories or work out their own answers, and one referred to the freedom to work independently. Three of the students thought the way the session was 'different' to a normal science lesson made it enjoyable, and three students specifically referred to the slides that had been shown (and another referred to the sessions being more 'visual'). Two students cited each of (i) the cutting and sticking activities, (ii) the hands-on nature of the activities, and (iii) the opportunity for free discussions.

The girls who were interviewed felt the sessions had been a good use of their time: as they 'got to choose', and the activities

> 'were quite hands-on as well, doing it yourself, rather than kind of, like answering questions or something, especially like the last two activities we did, we had to think about it, and then do something, rather than just writing it'.

The boys interviewed thought that the work on explanations 'was more interesting than normal science lessons'. They judged the difficulty of the work as 'just to the right level', a judgment apparently made with some metacognitive sophistication,

> ‘[be]cause it sort of ranged a lot as well, it varied a lot, you know, so … you’re learning different aspects of it, like, looking at different points of the subject, so you’ve got the whole thing as a whole overall, after doing all of the different ones, so you sort of put them all together and then you get the sort of main point of the subject … I think it helps to be able to see, so you can put it as different sides of the arguments, or different viewpoints, so that you can sort of work a way down the middle, work out what everything means if you put it all together’

Lessons from the lessons

Key aspects of the nature of science, such as the role and nature of explanation, need to be integrated into the teaching of science, as they are meaningless without scientific context. That said, the sequence of activities here (available on SEP, 2004) could be built into schemes of work – providing lessons focused on ‘explanation’, building upon existing content knowledge, and so developing an appreciation of this feature of science which can then be revisited and consolidated through reinforcement activities built into the teaching of subsequent topics.

There is always a limit to how much credence can be given to general points drawn from a case study of a single teaching episode, especially when evaluated and reported by the designer and teacher of the lessons. This is perhaps more so when the context is atypical: e.g. a visitor to school with the opportunity to work outside of a set scheme of work on a topic of choice. However, such cases can indicate potentially useful ideas and approaches to test-out in other contexts.

Here I would like to focus on the role of choice in the success of these activities. Choice was deliberately built into this teaching episode at a number of points. The most obvious way in which choice was used was in terms of giving options of topic. So in the introductory activity students could select which phenomena they wished to explain from a bank of options. In the sequencing activity, two different science contexts were offered for the task. In the critiquing exercise, there was a wide selection of examples that the pupils could select from to use in their work. In part this functioned to allow pupils to select areas of science where their interest engaged them, as well as where they felt sufficiently secure in their subject knowledge to be able to succeed (something that was clearly important for the girls interviewed).

A second way in which choice was given was in terms of the way that elements were offered in the sequencing activity. Students were offered components of possible explanations, but the options included both 'distracters' and redundant information. This meant that the task become open-ended, allowing the possibility of a range of different 'correct' (if not necessarily 'full') answers. The opening activity just offered questions, with no clue as to the science knowledge to be used – potentially very open ended (especially if explanations are judged in terms of being logical and building on science knowledge, rather than necessarily matching accepted science answers). The sequencing activity was more structured, offering all the main elements needed for an answer that would match curriculum science: yet it was not so-structured to provide all-and-only-all the pieces of a set puzzle.

The types of 'choice' made available to students made the lessons more learner-centred (see Chapter 5), and gave them more of a feel of control over their work, rather than just being given a task to do. Choices made tasks more open-ended, *and* potentially more creative. For example, on the sequencing activity, some groups developed complex multi-thread arguments where others offered a single logical chain. When invited to offer explanations for phenomena, students were able to seek out relevant connections with their background knowledge, and draw upon anything that seemed pertinent.

Choice can provide a means of 'differentiation by outcome' – a way of setting a common task that allows all pupils to succeed at appropriate levels. All the 14 year olds in these lessons were able to offer, sequence and critique explanations, but the range of outcomes was considerable. This type of choice allows each pupil to be challenged at a level where they can succeed, but without overtly labeling individuals (see Chapter 1). Some show considerable degrees of analysis, synthesis and judgment – others less so.

This, of course, begs a question. The 'teacher' did not know these pupils, and so made no assumptions about what each individual could be expected to make of the work. In this context each learner (within their pairs and groups) was able to take on a level of challenge that was comfortable. Normally a teacher would have to judge their role in guiding learners' choices. As pupils seemed to enjoy the lessons it seems *unlikely* many were deliberately working well below their potential (cf. Csikszentmihalyi, 1988). However, the approach relied on the pupils having enough metacognitive awareness and enough confidence in their abilities to regulate their own work. In this group there was certainly some evidence of metacognitive maturity – but this is not something that can always be taken as given, especially when many potentially gifted learners are known to habitually underachieve (e.g., see Chapter 3).

In conclusion, offering choice is recommended as a useful principle when planning lessons for the most able students. Choice *of topics* (where possible) engages learners, allowing them to link to interests and to demonstrate ability by selecting topics where secure background knowledge is available. Making even fairly structured activities as *open-ended* as possible allows creativity and gives opportunities for employing high-level cognition. Choice *of examples* can allow students of different levels of attainment, and with different strengths, to match the selected options to a level of demand that allows both progress in the task and enough challenge to facilitate useful learning.

However, offering gifted learners choice clearly implies delegating learners significant responsibilities - entrusting students to have the metacognitive awareness and motivation to regulate their learning. The use of such approaches assumes a learning environment where learners are accustomed to being trusted and exercising such judgment wisely.

Well-developed metacognition is often associated with the gifted (see Chapter 6), and clearly such trust may often be deserved, and rewarded (as in the case reported in this Chapter). As always, the teacher needs to monitor and scaffold learning, and judge when learners are ready to take on more autonomy in their learning. There is potentially a virtuous circle here: offering choice both assumes and encourages metacognitive engagement. As the present case study shows, pupils seem to appreciate being given choices in their learning, and many will thrive on the challenge, and take opportunities to engage in high-level thinking about science.

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