Activity 4: Explaining science

This activity explores the nature of a good scientific explanation.

Overview of learning activity

Explanations are a key focus of science. This activity, which develops an activity used previously at KS3, and published by SEP as part of materials on *Teaching about Ideas and Evidence in Science at KS3*, was used in ASCEND to encourage students to think about one feature of the nature of science, by considering the characteristics of a scientific explanation. The aim of the session was to help students

a) appreciate that explanations play a central role in science

b) to have criteria for 'good scientific explanations': in science explanations are expected to

i) be logical

ii) be based on evidence and/or accepted scientific ideas

iii) usually be consistent with accepted scientific knowledge

The session includes two activities. The first involves students working in pairs forming their own explanations for phenomena, and then swapping their explanations with another pair. The second activity involves evaluating a mooted set of explanations. The first activity is intended to provide students with an engaging activity that will get them thinking about explanations, and (by working with the explanations from another pair) and considering what makes a good explanation. The second activity reinforces this by asking students to evaluate mooted explanations.

Rationale for the activities

It is intended to use the two activities within the same session if sufficient time is available (i.e. the ASCEND sessions were 90 minutes long). However, the activities could be used in two successive sessions if less time is available for a session.

1. Introducing *scientific* explanations: 'suggest an explanation'

The first activity is designed to get students discussing possible explanations, and so provide a starting point for thinking about what a good explanation might be in the context of specific target phenomena. This activity is based around a large set of invitations to suggest an explanation for various phenomena. Although students may well know accepted explanations for some (from school, or informal science learning) the set was designed to include a wide range of phenomena for which most students would not have a ready-made explanation. It was known from using this idea in school with a top set Y9 (13-14 year old) science group, that most able students found this to be an enjoyable activity and that *the choice* of phenomena to explain had been appreciated.

The activity has been developed for use with most able KS4 (14-16 year-old students). In the version of the activity used in ASCEND and included on the CD here, students work in pairs to suggest explanations – discussing the merits of their ideas, before swapping their responses with another pair, and offering each other feedback on the strengths and weaknesses of their ideas.

The set of questions provided has been designed to:

- Cover a wide range of topics;
- Include some examples unlikely to have arisen in science lessons;
- Offer some questions that can have explanations at different ‘levels’ of explanation;
- Include questions intended to encourage students to think ‘out of the box’.

It is certainly *not* expected that students will know current scientific explanations for all the phenomena. The aim of the exercise is to give a context for thinking about the characteristics of a good scientific explanation, rather than whether students can *recall* explanations they have learnt.

Some of the ‘explanations wanted’ (there are 50 in the set) were for:

- Why is sea water salty?
- Why don’t people lay eggs?
- Why does salt dissolve in water?
- Why do elastic bands stretch?
- Why do people have hairy armpits?
- Why are there 24 hours in a day?
- Why are only 3 elements (iron, nickel & cobalt) strongly magnetic?
- Why don’t insects have lungs?
- Why do people age?
- Why do acids turn indicators red?
- Why don’t fish have arms?
- Why do we each have 2 nostrils?
- Why do knees only bend one way?

Clearly it is unreasonable to expect secondary students to have scientifically valid understandings of (for example) the origins of ferromagnetism: but such questions have been included as an opportunity for students to think around issues, and explore their understanding (in a way that may not commonly happen within the confines of GCSE classes). Attempting to explain something like the absence of lungs in insects can clearly link to a range of relevant school science ideas. Teachers should not be concerned if they feel they can not offer satisfactory explanations in response to some of these 'why' questions: nor can the author (it being easier to pose than answer such questions!) It is considered here that it is very important that students do not get the impression that science is about closed questions, and all the major puzzles already have answers. (Such a view is likely to discourage the most curious from looking to science as a career direction.)

Some questions may certainly be seen form different perspectives. An explanation for there being 24 hours in a day could either be about why the earth takes the time it does to spin, or about why the day would be divided into 24 equal periods (rather than say 10 or 100 or 25).

Most questions can be answered at several different levels of understanding, and this is important in coming to understand the qualities of a scientific explanation. So, for example, the sea is salty because it contains a lot of dissolved salt, and salt dissolves in water because it is soluble. These are explanations in a sense, but do not help us understand the phenomena much better. Indeed, using a label such as 'soluble' is little more than a tautology (in responding to that particular question) if that is simply how we label substances that dissolve in water. These type of responses invite a further 'but why?'.

Similarly, to say that *humans do not lay eggs* because they are mammals is pretty limited in explanatory terms – but sadly may well reflect just the kind of answers we are training students to provide in school science!

Many students seem not to have the 'epistemic hunger' of wanting to take explanations further: but this is one area where we should expect the gifted to persevere until they are satisfied they understand a question.

A question such as *why our knees only bend in one direction* clearly has several possible types of answers. It can be answered in terms of anatomy and physiology: the structure of the joint, and the functions and properties of bone, muscle, tendons etc. It also has a developmental answer: how bodies grow to work that way. And, as always in biology, there is the evolutionary explanation – why we have evolved to have such a joint (which is clearly different in nature to the hip joint) in that position.

Even scientists may be criticised for sometimes presenting 'evolutionary just so stories' – explanations for how and why certain traits or structures have evolved based on what seems feasible rather than deriving from a strong evidence base. It is useful for students to learn to appreciate how feasible explanations, consistent with what we know, may turn out to be refuted as further evidence comes to light.

2. ‘Good’ and ‘poor’ scientific explanations

The second activity is one that had previously been found challenging by top-set Y9 students. This involves the students, working in groups, considering a set of prepared explanations (many designed with specific flaws – some more subtle than others) and selecting examples of good and poor scientific explanations.

This is a high level activity according to the taxonomy of thinking skills (see Chapter 3). The students are asked to give their reasons why particular explanations are judged to be poor. For this activity, the students are provided with some suggestions about what makes a good or poor scientific explanation. Teachers may decide to only allow students access to this support material after they have spent some time working on the exercises based on their own ideas.

The main resource for this activity is a set of mooted ‘explanations’ of various scientific worth, for students to critique. (The materials also include templates for photocopying as A3 sheets for answering the exercise.)

Magnesium oxide is produced when magnesium is burnt in air as burning is a chemical reaction with oxygen.

Example 1: *Why is* magnesium oxide produced

> ***‘if I suddenly created a new science with all . . . terminology . . . okay, say you’ve* never *heard of a window . . . say . . . you don’t know what a surface is . . . and you start talking about surfaces . . . say you start talking about . . . say you don’t know what evolution is, and you start talking about evolution, that’s all very well. But you* – don’t – know – *what – evolution – is, so you’d have to know the* context *for it to be good science. If we assume they know the context . . . if we assume they know what an oxide is, that they know . . . what magnesium is, that they know what burning is and chemical reactions and things . . . because . . . who are you explaining to . . . ?’***
>
> *(An ASCEND delegate considers the importance of audience in judging an explanation)*

As with most of the ASCEND activities, there is plenty of scope for individual teachers to modify the set – perhaps by adding some of their own examples (especially useful to highlight dubious explanations that have arisen in class, or to focus thinking on recent topics.)

The set of explanations is designed to include examples of common types of flaws in arguments, as well as more sound examples. It is important to note that although some of the examples are clearly ‘wrong’ from a scientific viewpoint, others offer various degrees of sophistication.

A lever can be used so that a small force moves a large weight, thus using less energy than moving the weight directly.

Example 2: An explanation that contradicts scientific principles

> We always see lightning before hearing the thunder because the lightning sets off a process in the cloud that builds up to a thunder rumble.

Example 3: A feasible explanation that is inconsistent with scientific knowledge

Although the activity asks students to identify examples of good and poor scientific explanations, and justify their choices, it is not intended that students come to think that explanations are either *good* or *poor*. As with most of the ASCEND activities, the final outcome is less important than the process of debate and argument through which students explore the activity.

For example, the following explanation is logical:

> The apparent movement of the stars through the night sky suggests that either the earth spins round, or that the rest of the universe rotates around the earth.

Example 4: A thought-provoking explanation

That the former option (the spin of the earth) is currently accepted in science does not make the other possibility logically incorrect – although application of Occam's razor suggests that the movement of the earth is a better option, as it is a simpler explanation. Gifted students (especially pedantic ones) could point out other logical possibilities: the stars revolve within an otherwise fixed universe; some sort of field around the earth deflects light from the stars in such a ways as to give the appearance of relative motion… For the purpose of this activity, exploring the strengths and weaknesses of explanations is more important than knowing which explanation is currently believed correct.

Scaffolding for students

Teachers using these activities will need to decide how much help in the way of hints and suggestions to give students, and at what points to provide any support. The resource materials on the CD offer two useful sheets. One offers guidance on what an explanation is in relation to other key ideas (see the figure). This sheet may also be useful in supporting some of the other ASCEND activities that discuss laws and models.

Some ideas about Science

Science is about ***understanding*** (making sense of) the world (i.e. the universe in which we exist, not just the earth).

We try to understand the world by developing ***theories*** that enable us to explain what happens, and what might happen in the future (under various conditions).

An explanation is an answer to a 'why' question. A scientific explanation uses scientific ideas (such as theories) to answer questions.

A **theory** is a way of explaining the relationship between different things. Theories are developed by scientists in response to their ***observations***.

Information collected during observations and experiments are called **data**. When we observe a regular pattern in our data, we sometimes call this a '**law of nature**'.

Before scientists can carry out an experiment, they must already have an idea of what the ***relationship*** might be.

An idea about a relationship that has yet to be tested is called a **hypothesis**. To ***test*** a hypothesis scientists must design an **experiment** and ***predict*** what the outcomes would be if the hypothesis is correct. There are always lots of possible hypotheses that could explain any observation, so an experiment can never ***prove*** a hypothesis is the correct one. Experiments are subject to ***errors***.

Scientists often try to ***simplify*** what they are studying by making **models**.

Figure 4.1: Information provided for students

Finding flaws in explanations

The second guidance sheet included offers ideas on evaluating explanations in science. The students are informed that an explanation may:

- seem logical, but not actually answer the question asked
- seem logical, but be based on false information or use principles that scientists do not accept
- be illogical, so that the steps in the explanation do not follow on from each other

Some of the explanations included in the examples for students are sound, but may require some thinking though.

It takes the Earth about 23 hours and 56 minutes to turn once on its axis compared with the distant stars. However, because the Earth orbits the Sun as well as spinning on its axis, it needs to turn further before it faces the same way compared to the sun. Each day the Earth moves about 0.25% around its orbit, and so the Earth needs to turn for an extra 4 minutes (0.25% of a day) to return the same face to the Sun. One day is therefore taken to be 23 hours 56 minutes + 4 minutes = 24 hours.

Example 5: A sound scientific explanation

Others may be best considered partial explanations. For example, the albedo of Venus (about 65%) is higher than Pluto (about 40%), so the following explanation 'makes sense'.

> The planets reflect the sun's light, but some planet surfaces reflect a larger proportion of the light reaching them. Pluto is much less bright in the sky than Venus because Pluto's surface reflects a smaller proportion of the sun's light.

Example 6: An incomplete explanation

However, such an explanation is - at best - partial. Pluto is much smaller than Venus (about a fifth the diameter), so has less surface reflecting; is much farther from its source of illumination (about 50 times as far from the sun), and is much farther from us as observers. The difference in albedo is a fairly minor factor by comparison.

The students are also provided with some examples of common types of flaws that may be found in 'scientific' explanations:

- re-labelling – giving an explanation which is just a renaming of the thing to be explained
- tautology – when the thing to be explained is assumed in making the explanation
- anthropomorphism – when human feelings and motives are used to explain the activity of non-humans
- animism – when inanimate objects are treated as if they were living
- teleology – explaining in terms of objects and processes having some purpose

A number of the examples of mooted explanations provided demonstrate these types of flaws.

> metal objects will often 'ring out' when struck, because metals are sonorous.

Example 7: An 'explanation' that simply labels the phenomenon to be explained

> Electrical appliances are often 'earthed' as a safety precaution in case any wires become disconnected inside. The earth connection protects people from electrocution as the charge wants to travel to earth through the easiest path.

Example 8: An explanation that uses anthropomorphism

There was very little oxygen in the atmosphere of the early earth, and only very simple life was possible. The oxygen in the air is mostly a by-product of living things. Organisms evolved that produced oxygen so that more complex animals and plants would be able to evolve.

Example 9: An explanation that is teleological: suggesting that nature has a purpose

Resources

The following resources are included on the CD:

Resource	Description	Filename
Instructions for 'suggesting explanations'	Instructions for first activity: groups of 4 students to work in pairs on developing and then offering feedback on explanations	Act 4 Instructions 1
Suggest an explanation	A set of invitations to explain a range of phenomena – students select from these for the first activity	Act 4 suggest
Ideas about science	A simple 'one side of A4' introduction to some key terms in science – explanations, and how these relate to theories, laws, data and hypotheses.	Act 4 Ideas about science
Explanations about science	A 'one side of A4' introduction to explanations in science, including criteria for judging explanations.	Act 4 Explanations about science
Spotting the flaws in explanations	A 'one side of A4' summary of common flaws in explanations, including tautology and teleology.	Act 4 Flaws
Instructions for 'judging explanations'	Instructions for the second activity: evaluating examples of prepared explanations	Act 4 Instructions 2
Explanations to judge	A set of explanations of variable scientific value for students to critique and evaluate	Act 4 to judge
Good explanations	Sheet to be produced A3 size for students' selected examples of good scientific explanations	Act 4 good
Poor explanations	Sheet to be produced A3 size for students' selected examples of good scientific explanations	Act 4 poor