Analogy – constructive or confusing? A students' perspective

Ben Styles

Teachers often use analogy to explain scientific principles and may also favour its use with less able students. Do we have a full appreciation of how and when to use analogy?

Analogy as a mode of explanation

The use of analogy as a mode of explanation is common in the classroom. Teachers will use anything from a short, simple everyday-life analogy to illustrate a scientific principle, to a well established one that is traditionally used in the classroom (for example, the Rutherford-Bohr model of the atom being like the solar system).

Dagher and Cossman (1992) provide a study on the distribution of explanation types used by individual science teachers in the classroom. Analogy is seen as one mode among many (Figure 1). They found that with a class of 12–13 year-olds analogy was used in about 10% of explanations, and with 13–14 year-olds in about 18% of explanations. The effectiveness of analogy use is clearly worthy of research as it makes up a substantial proportion of explanations used.

ABSTRACT
It is easy to use analogy in the classroom without much thought as to whether it is helping or hindering students' understanding. This article starts with a review of the theory behind analogy use. The results of a questionnaire given to 82 mixed-ability 14–15 year-olds indicate whether students prefer analogical to factual explanations. Teachers' assumption that analogy with everyday-life experience is helpful in promoting understanding of scientific principles by less able students is questioned. Analysis of 14–15 year-old students' work highlights the dangers of analogy misuse and 11–12 year-olds' work reveals only the most able using analogy effectively.

It seems logical to use phenomena that students have already understood or experienced to illustrate new scientific concepts. Indeed, as a trainee teacher, I was often encouraged to use more examples from everyday life in teaching. If knowledge is constructed on the basis of pre-existing knowledge (Driver, 1983) then the scope for the use of analogy in teaching is necessarily huge. Perhaps, then, its use should be advocated on a larger scale than that which Dagher and Cossman (1992) found. Treagust, Duit, Joslin and Lindauer (1992) suggest that opportunity for the full use of analogy in the classroom is not always taken. This study improves on that of Treagust *et al.* (1992), taking views of the students into account by means of a questionnaire. Students' preferences for particular types of explanation give a valuable insight into how effective each type is.

Holyoak and Thagard (1995) advocate that analogy provides a potential tool for jump-starting students by introducing unfamiliar 'targets' (novel ideas) in terms of more familiar 'source analogues'. They claim that good teachers frequently use analogies to render unfamiliar matters comprehensible to their students. They make the valid point that chemistry teachers are particularly fond of analogy – the *Journal of Chemical Education* having a regular feature 'Applications and Analogies'.

The development and use of analogy

The cognitive mechanisms that occur when constructing an analogy can be complex. Therefore, it might be expected that only the more able students can come

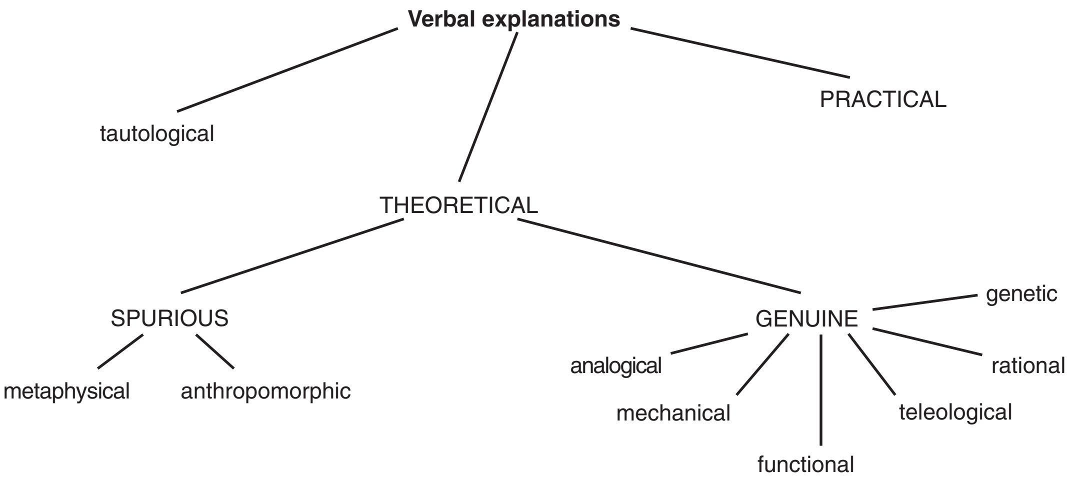

Figure 1 Modes of explanation (from Dagher and Cossman, 1992).

up with their own analogies. Holyoak and Thagard (1995) divide the process into two main parts: the selection of an analogue and its application to its target (Figure 2).

The selection of the analogue can be done in four ways. It might be noticed by accident – this might occur during the course of a lesson when a teacher happens upon an analogy on the spot to illustrate a new concept. It might be retrieved from memory – as is perhaps done when the teaching of a new topic is being planned. The analogue could intentionally be compiled to suit the target, possibly leading to an unusual analogue. Finally, the analogue could be ‘constructed’. In this case the new analogue could go beyond both the target and what is known already. This latter case is perhaps more applicable to scientific discovery. When Kekulé imagined a snake biting its tail to represent benzene, the new source did go beyond the target and what he knew, providing a structure – the snake rendered circular – that inspired the hypothesis of benzene’s ring.

Several studies suggest what the teacher should consider when embarking on the use of a new analogy. Gilbert, Boulter and Rutherford (1998) require that

analogy	a simile or metaphor used to explain an idea or concept
analogue	the familiar idea being used as an explanation
target	the idea being explained
mapping	the application of analogue to target

Analogical terms are easily clarified when applied to a particular example analogy. The enzyme/scissors analogy is as follows – terms used in this article are in bold:

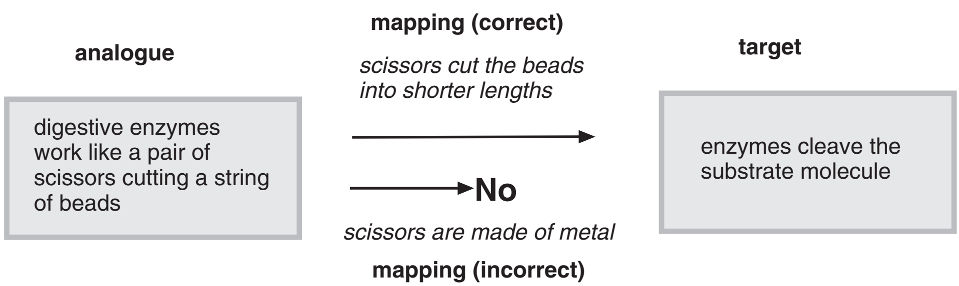

Figure 2 Terms used in analogical theory.

the use of teaching models (including analogies) satisfies many criteria. They suggest that models are used in the light of students' alternative conceptions, which is clearly important from a constructivist perspective. Models should be taken from a familiar source (familiar analogue) and should be 'overtly presented'. They should be used with other sources and alongside student-generated models. Most importantly, Gilbert *et al.* (1998) emphasise that models should have the appropriate use of 'structure mapping' – only relevant aspects of the analogue should be applied to the target. The application of the analogue to the target idea (mapping) should not be undertaken lightly (Figure 2). Indeed, this is when most pitfalls occur and hence is where most caution is needed. Holyoak and Thagard (1995) also highlight that the teacher must emphasise which components of the analogue are actually relevant to the comparison between analogue and target.

Pitfalls in using analogy

> *Analogy is a double-edged sword in that it may totally mislead learning since an analogy is never based on a total one-to-one fit between analogue and target.* (Glynn *et al.* (1989) in Treagust *et al.* (1992))

Holyoak and Thagard (1995) state that a good analogy should be strong in similarity between the analogue and its target. They also suggest that the analogue must have sound structure and purpose. Failure on any one of these counts can lead to confusion. They acknowledge that on introducing a complex and new idea, a superficial analogy can be seriously misleading. If irrelevant aspects of the analogue are mapped to the target idea then the analogy is negative and the result is a bad explanation (Hesse (1966) in Gilbert *et al.* (1998)).

Tailoring analogy use to the type of student

It might be reasonable to assume that our use of analogy should be tailored to the teaching context concerned. Perhaps it should depend on the age or ability of the class/student being taught. In order to understand a novel concept, less able students may require examples from everyday life with which they are familiar. The more able may understand without such parallels being drawn.

Three studies were used to explore the use of analogy:

Study 1: Problems with analogy use
The aim of this study was to highlight pitfalls resulting from careless analogy use.

Study 2: When to use analogy – the students' perspective
Gilbert *et al.* (1998) ask the question: *'How do science students go about the process of understanding the explanation with which they are supplied in terms of their own prior knowledge and need?'*, suggesting that there is little evidence on this subject. The second study confronted possible disparities between teachers' preconceptions of when to use analogy in the classroom and the views of the students. It was a pilot study, which might contribute to a guide of when and how analogy should be used in teaching.

Study 3: Understanding analogy
The final study was provoked by the results of Study 2. The aim was to ascertain a relationship between ability of students and their capacity to make correct sense of a specific analogy.

Study 1: Problems with analogy use

Method
In a lesson on digestive enzymes with an able class of 32 14–15 year-olds, the analogy of an enzyme being like a pair of scissors was used. This was done both vocally and visibly using joined beads and fingers. Towards the end of the lesson, the denaturing of enzymes was discussed. The scissors analogy was taken one step further (mapping another aspect of the analogue to the target – see Figure 2). It was said that if the enzyme was denatured then *'it was like the pair of scissors getting bent or broken, meaning they were no longer able to function and could not break the beads/molecule'*. This was backed up with the actual shape of an enzyme and how it would change on denaturing. A piece of homework was set: *'On a plain sheet of paper, draw and label how a digestive enzyme works as if you were trying to explain it to a 11–12 year-old pupil'*. Students were asked to include information on what happens if it denatures.

Results
Some very clear, well-presented and accurate posters were received. However, it was also clear from some that misunderstanding had ensued and that this had sometimes been promoted by the use of analogy.

The following students demonstrate the variety of responses of the class and provide an appreciation of the analogy's effectiveness (no previous teaching had taken place on this subject):

- Amanda thought that the enzyme itself is broken down when it is denatured. This could have been inferred from the idea of scissors breaking (Figure 3).
- Brian used a visual representation of scissors cutting a fat molecule.
- Catherine uses the analogy effectively, stating: *'The enyzme that normally acts like a pair of scissors has become bent and will no longer cut properly because of the heat'* (Figure 5).
- Edward made a curious statement: *'So this time, instead of having the pair of scissors chopping up the food, the scissors are bent and rusty and no longer able to cut food down into small enough sized pieces to fit through holes'*. The student was either playing around with the analogy or genuinely misunderstood.
- Fiona was provoked to think of her own analogy to illustrate what she was trying to show. She pictured the enzyme with a smiling face at room temperature and then made it look disgruntled at 100 ºC (Figure 4).
- Ian wrote that *'enzymes are biological scissors'*. This could either mean that he did not appreciate that an analogy was being used at all or he could have missed out the word 'like' in his writing (Figure 6).

Discussion

The first of Holyoak and Thagard's (1995) four ways of formulating an analogue applies to this example of analogy use with 14–15 year-olds. When a denatured enzyme was considered to be like a broken or bent pair of scissors, the analogue had been 'noticed'. No thought had been given to what aspects of this analogy should be mapped because it had been thought of in the classroom and consequently this was not addressed in the lesson. Many of the problems illustrated above could have been avoided if the correct mapping had been emphasised or even if the analogy had not been used at all. Teachers should be very cautious when they think of analogies on the spot like this – they should back them up with details about what should be mapped from analogue to target. The 'scissors analogy' shows the problems that might result if this is not done conscientiously.

Figure 3 Amanda's response.

Figure 4 Fiona's response.

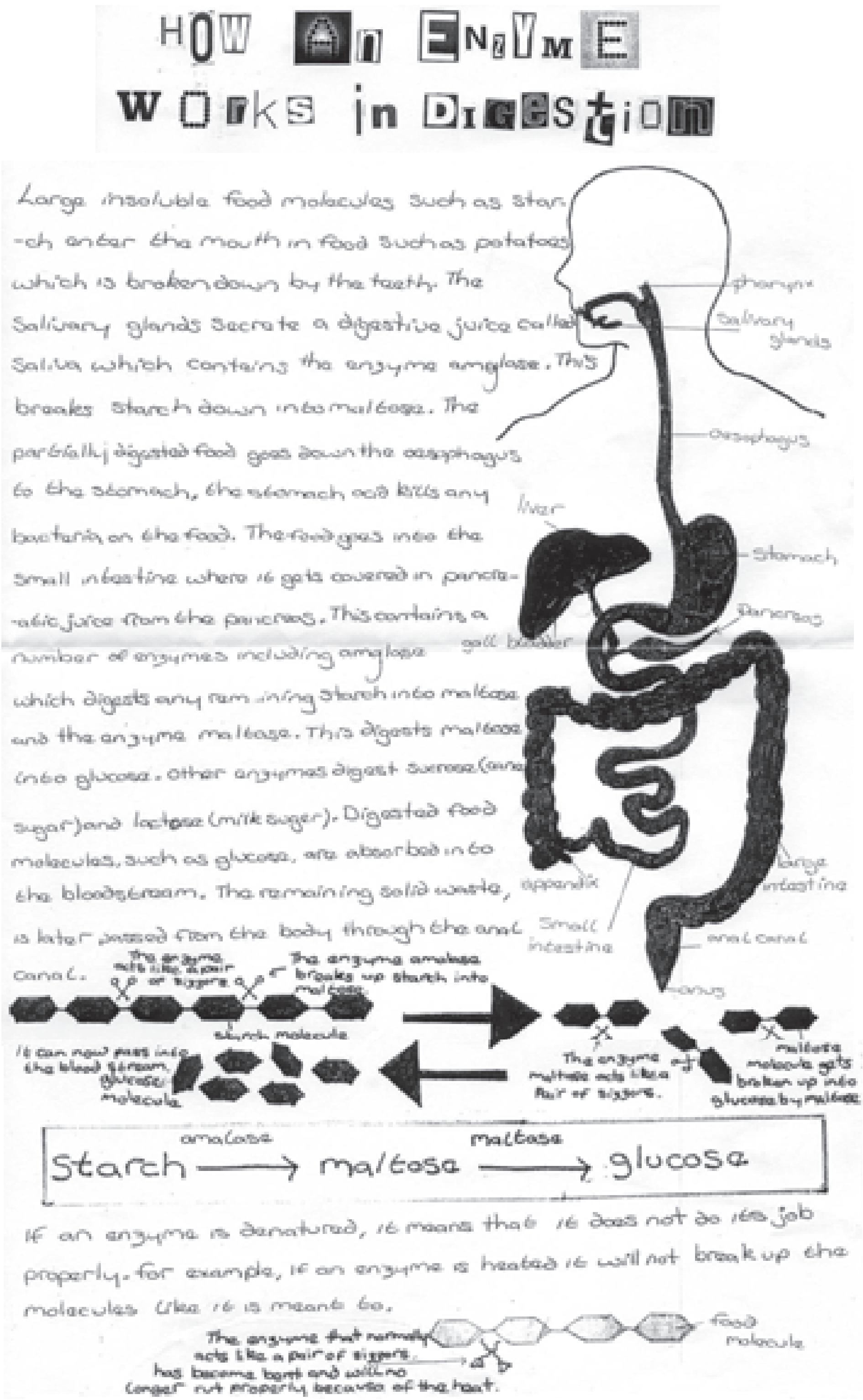

Figure 5 Catherine's response.

Figure 6 Ian's response.

Teacher questionnaire

Name:________________

Please answer the following questions as fully as you have time to and return this sheet to me as soon as possible.

1. Give three examples of analogies that you use when teaching. Only include ones that you think are very successful in promoting students' understanding.
2. Do you know of any analogies that you have used that seem to confuse rather than help students (e.g. analogies that fall down if you take them too far)? If so, please describe.
3. Do you use analogies with younger students that you would avoid using with older students and vice versa?
4. Do you think you use more analogies with less able than with more able students? Why?
5. Do you think a study on analogies and their effectiveness in helping understanding would be useful?

Figure 7 The questionnaire given to science teachers.

Study 2: When to use analogy – the students' perspective

Method

This study centred on two questionnaires: the staff questionnaire (Figure 7), which ascertained when most staff would use analogy in their teaching and the student questionnaire (Figure 8), which looked at student preference of analogical versus non-analogical explanations.

The staff questionnaire was given to all ten science teachers at an 11–18 comprehensive school.

The student questionnaire, consisting of ten pairs of statements, was given to 82 (38 male, 44 female) 14–15 year-old students of mixed ability. One statement of each pair explained a scientific concept using an analogy and the other used a factual explanation. Students were asked to choose which explanation in each pair they found most helpful in explaining the concept. Each time they chose the analogical explanation instead of the factual explanation they were allocated a point – giving a 'preference score' out of ten. The preference scores were then correlated with ability. Male and female preference scores were also compared.

Results

Five experienced science teachers' views were collected from the staff questionnaire. Staff were found to use more analogies when teaching less able groups. Analogies were thought to *'simplify for the less able'*, there was a *'need to relate to something [the students] know about'* and *'less able students find analogies more concrete/real than abstract concepts'*. It was thought that *'more formal models are accessible to the more able'*.

All students completed the questionnaire. The mean preference score was 4.6 out of 10 (± 2.7 standard deviation): students preferred non-analogical and analogical explanations in roughly equal amounts. The diversity of preference score (shown by the high standard deviation) shows that the questionnaire was good at teasing out the different preferences students had about analogy. Indeed, a whole spectrum of preferences was found: from students preferring no analogies to some preferring all analogical explanations (Figure 9). This emphasised the need for consideration of many modes of explanation to satisfy every student's needs. It is possible that differing experience of the analogies used (some may have been familiar) may have influenced students' preferences.

Pupil questionnaire

Here is a list of pairs of statements. For each pair choose which one you find more helpful to your understanding. Place a tick over the ones that you choose. Underline any words that you don't understand.

A cell is like a brick in a house. It is a unit that builds an organism.	Organisms are made up of units called cells.
Long-chain hydrocarbons make viscous liquids because their molecules get tangled up and hence are hard to pour.	Long-chain hydrocarbons make viscous liquids as their molecules are like spaghetti and are hence hard to pour.
Digestive enzymes are like a pair of scissors – they cut up food molecules for absorption.	Digestive enzymes are proteins, which bind to food molecules and catalyse their breakdown.
An enzyme denatures when its protein structure is disrupted – preventing it from working properly.	Denaturing an enzyme is like bending a pair of scissors – they don't work any longer.
Electricity flows round a circuit like water through pipes of a central heating system. The pump is like the battery.	Electricity flows round a circuit. It is powered by a battery, which causes current to flow round a circuit.
Diffusion is similar to young children being released from a classroom at break – they eventually fill the playground.	Diffusion is the movement of a substance from an area of higher concentration to an area of lower concentration.
Concentration is a measure of how much solute there is in a fixed volume of solution.	Concentration can be likened to the number of people in the Grafton Centre at any one time. Saturday afternoon represents a high concentration and Thursday night represents a low concentration of people.
The frequency of collisions between particles of solute depends on the concentration of the solution. A high concentration gives a high frequency of collisions.	If solute particles are represented by people; the Grafton centre on a Saturday afternoon represents a high concentration of people and collisions between them are frequent.
The nucleus is to the cell what London is to England. It is the control centre.	The nucleus controls the running of the cell.
Respiration occurs in mitochondria – hence they provide the cell with energy.	Mitochondria are like the powerhouses of the cell – providing it with energy.

Figure 8 The questionnaire given to 82 14–15 year-olds.

However, this does not detract from the diversity that was observed.

The Pearson correlation coefficients showing the relationship between analogy preference and ability, as indicated by scores for key stage 3 SATs (science examination done by 13–14 year-olds), show a significant negative correlation for the higher tier and a weak (non-significant) correlation for the lower tier (Figures 10 and 11 show scatter graphs for these data): implying that the more able might prefer fewer analogies. This would appear to support the reported choice of using more analogy with less able students – a strategy which seemed to be used by most of the teachers asked. However, the diversity of preference

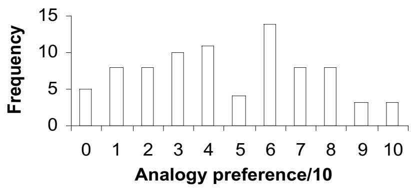

Figure 9 A broad spectrum of analogy preference for 82 14–15 year-olds.

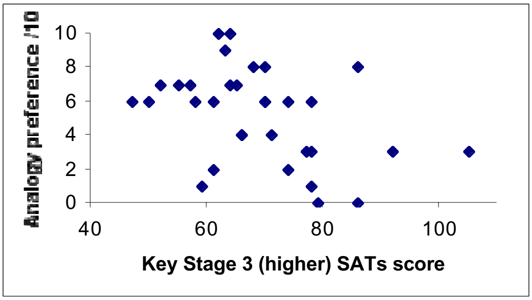

Figure 10 A scatter graph showing scores for key stage 3 SATs (science examination done by 13–14 year-olds) *vs*. analogy preference for 32 higher tier 14–15 year-olds (occasional points represent more than one student). Pearson correlation coefficient $r = -0.42$ (significant at $p < 0.05$).

advocates non-exclusive use of analogy. It does perhaps make sense that the more able can cope with the more rigorous scientific explanations on the questionnaire – although this may not be the cause of their preference for non-analogical explanation. It may also be worth considering that the more able might prefer more complex analogies to those tested or simply analogy used only for more complex concepts.

Gender does not seem to have a significant effect on analogy preference (Figure 12). However, the results showed a trend with the boys having a slightly lower preference score than the girls. This was the received impression from some of the more vocal boys, who seemed to be insulted by the analogies.

Discussion

The opinion of the teachers that analogies should be used less with more able students is backed up by Treagust *et al.* (1992). They suggest that often academic or upper school students are taught in the 'traditional way' – using definitions and pictorial illustrations. This policy seems largely unjustified by empirical evidence concerning the effectiveness of analogy use (Gilbert *et al.,* 1998). To advocate this biased usage, it is necessary to show improvement in less able students' understanding when taught analogies as compared to non-analogical explanation (more specifically, this improvement must also be absent for more able students). This study looked at students' choice of analogical versus non-analogical explanations as a measure of which gave the greatest understanding. The results for the higher tier appear at first to support biased usage. However, the diversity of preference was so great that some of the more able students would be disadvantaged if analogy was not used with them. The lack of a significant correlation for the lower tier of this group backs up the argument that our use of analogy should not be influenced by the ability of the class. However, any concrete conclusions of this sort would have to be made after a study involving many more students, using a better measure of ability and of their understanding gained.

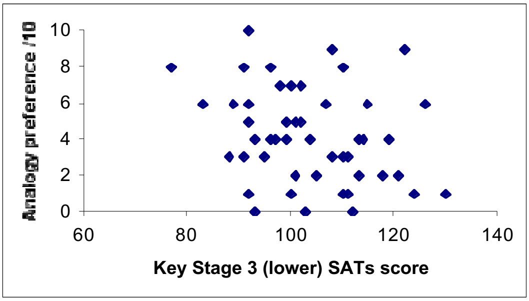

Figure 11 A scatter graph to show scores for key stage 3 SATs *vs*. analogy preference for 50 lower tier 14–15 year-olds (occasional points represent more than one student). Pearson correlation coefficient $r = -0.23$ (not significant).

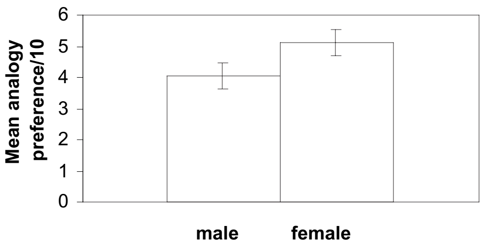

Figure 12 Mean analogy preference for 38 male and 44 female 14–15 year-olds. Bars indicate ± 1 standard error. *T*-test $p = 0.065$ (not significant).

This might be done by teaching a novel concept using analogy to one class of high ability and the same concept without using analogy to a different class of the same ability and then testing their understanding. This would then be repeated with two classes of lower ability. If the effect of analogy use is more beneficial to the understanding of low-ability as compared to high-ability students, then biased usage might be justified. However, it is likely that diversity of performance in each group would advocate the use of more than one type of explanation.

As a result of the questionnaire in this study, it might be worth considering other effects that might explain student responses. As indicated above, the cognitive mapping mechanisms involved in analogies may actually be quite complex. In order to understand the spaghetti/long-chain hydrocarbon analogy in the student questionnaire (Figure 8), it has to be appreciated why some hydrocarbon molecules can be regarded as chain-like, how this maps to spaghetti strands, how spaghetti pours and why this might explain why long-chain hydrocarbons are viscous. This cognitive process is quite complex and it might be reasonable to assume that lower ability students would just be confused by this analogy rather than finding it helpful. Perhaps a simple mechanical explanation (Figure 1) might be more useful here, for example, *'the long molecules in the liquid get tangled up in a mess and the liquid is therefore hard to pour – we call this viscous'*. This may not, however, result in the same depth of understanding.

Observation of the Piagetian levels of the individual 11–12 year-old students who completed a similar questionnaire provoked doubt as to how well the students understood the analogies that were being used. These levels had been assigned through the Cognitive Acceleration through Science Education (CASE) scheme – see Adey and Shayer (1994). Since the students were just asked to choose the type of explanation they preferred, they may not have necessarily understood the complete, or, indeed, correct picture from the analogy. For this reason it was necessary to look at the students' understanding of one particular analogy.

Study 3: Understanding analogy

Method

During an introductory lesson on living cells to a mixed ability class of 11–12 year-olds, the following analogy was used: *'A cell is like a building block of a house; just as a house is built up of things that carry out different functions, an organism is built up of cells that do different things'*. Using this analogy the teacher is able to ask questions such as 'Would you use the same blocks to build the windows, walls and roof?' The idea of cells carrying out different functions can become apparent with such an analogy.

For homework, the students had to complete a worksheet on the functions of parts of a cell and then write a short passage on the answer to 'What is a cell?'.

Results

The following seven students represent the ideas that were present within the group (no previous teaching had taken place on this subject):

- Some students used their ideas of a cell, which they had gleaned from the analogy, to construct their own suitable definitions and analogies. Amy described a cell as *'the smallest unit of an organism that is able to function independently'*. Chris (one of the most able) described animal cells as *'ice-filled balloons'* – a particularly apt analogy.
- The most able students used the analogy exactly and then backed it up with their own ideas of what a cell is. Graham stated *'Cells are the building blocks that make all living organisms. Cells are all different shapes and sizes. Different cells share the same general parts.'*
- Some students might have used the analogy to arrive at their definition but it was hard to tell. Henry stated *'A cell is tiny...cells have different parts to them...they're all different shapes and sizes...'*.
- Brenda and Jane confused the hierarchy: cell, organ, organism. They wrote *'Cells are a living organism and are found inside a living thing'* and *'A cell is one of our organs. It's an organ where blood is stored in our body'*. To talk about the building blocks as cells, the room as the organ and the house as the organism might have had better results, the analogy having more potential than originally conceived. This again comes back to the idea that it is essential that it is made clear what parts of the analogue are to be mapped to the target idea (Figure 2).
- Deborah was a more visual learner and was influenced by the slides of different cell types (shown at the end of the lesson) and hence may have ignored the analogy. She stated *'...well you can get all different cells and cells are all different shapes and sizes and colours'*.

- Kirsty was keen to make her own visual analogies, which will help her remember what an animal cell and plant cell look like. She may not have benefited at all from the building-block analogy, however. She wrote *'A cell comes in all shapes and sizes and I think a plant cell looks like a sink and a animal cell looks like an egg'*.

Discussion

With this breadth of response, it is clear that the use of a single analogy is certainly not going to be effective for everyone in the class. It is quite revealing that only the very able seem to be using the analogy, as they heard it taught, to help with their understanding of a cell. This may contravene what seemed to be largely believed by the teachers – that analogy might be more useful for the less able. Otherwise, it could simply be that the most able can express their understanding better in writing – for this reason this study does not provide a conclusive appreciation of understanding by all abilities in the class. Further work might ascertain what understanding the less able *do* gain by use of the analogy and whether it is more beneficial than other modes of explanation.

Implications for teaching

Gilbert *et al.* (1998) highlight the lack of research in the area of understanding explanations. This study was aimed at measuring students' understanding to determine the effectiveness of analogical explanation. The general conclusion of this work is that it is the responsibility of the teacher to teach new ideas in every way they can to cater for the needs of all the students in their class, a model within which analogy would occupy a small, but important, role. The following specific conclusions need emphasising. It is hoped that teachers can incorporate these findings and those of similar studies into the classroom and make appropriate adjustments to their teaching.

- The assistance of analogy to the understanding of all students is by no means definite.
- The use of analogy is not necessarily more helpful to lower ability students.
- Analogy should be used with great caution so as not to confuse students who are often tempted to extrapolate irrelevant aspects of the analogue.
- Analogy should be used in conjunction with other modes of explanation to cater for all students' needs.

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