Analogies in Biology Education: A Contentious Issue

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DARWIN saw the patterns of classification of life on Earth as a dynamic system, rather like the growth of a great tree. He felt that this kind of classification could be explained through inheritance and natural selection and he wrote in the *Origin of Species* an emotive analogy painting a picture of his vision in the passage below:

> *The affinities of all the beings of the same class have sometimes been represented by a great tree. I believe this simile largely speaks the truth. The green and budding twigs may represent existing species; and those produced during former years may represent the long succession of extinct species. At each period of growth all the growing twigs have tried to branch out on all sides and to overtop and kill the surrounding twigs and branches, in the same manner as species and groups of species have at all times overmastered other species in the great battle for life. The limbs divided into great branches, and these into lesser and lesser branches, were themselves once, when the tree was young, budding twigs; and this connection of the former and present buds by ramifying branches may well represent the classification of all extinct and living species in groups subordinate to groups. Of the many twigs which flourished when the tree was a mere bush, only two or three now grow into great branches, yet survive and bear the other branches; so with the species which lived during long-past geological periods, very few have left living and modified descendants. From the first growth of the tree, many a limb and branch has decayed and dropped off; and these fallen branches of various sizes may represent those whole orders, families, and genera which have now no living representatives, and which are known to us only in a fossil state. As we here and there see a thin straggling branch springing from a fork low down in a tree, and which by some chance has been favoured and is still alive on its summit, so we occasionally see an animal like the Ornithorhynchus or Lipidosiren, which in some small degree connects by its affinities two large branches of life, and which has apparently been saved from fatal competition by having inhabited a protected station. As buds give rise by growth to fresh buds, and these, if vigorous, branch out and overtop on all sides many a feebler branch, so by generation I believe it has been with the great Tree of Life, which fills with its dead and broken branches the crust of the earth, and covers the surface with its ever branching and beautiful ramifications.*
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> Darwin, *The Origin of Species*, 1967, p. 126

This passage is rich in imagery unexpected in a piece of scientific writing. Why did Darwin include such an extended analogy by relating his ideas about evolution to a large, branching tree? Was it to create a beautiful piece of prose to fascinate and motivate his readers to read more, or was the intention to help his readers visualize this abstract and new idea of evolution? We may never know the answer, but it does raise the issue of analogies in biology and biological education. Can analogies in biological education serve a useful function or are they a literary device that can cause unwarranted confusion when used in a scientific context? The purpose of this article is to illuminate the debatable answers to these questions. First, some examples from history will be explored, and the positive and negative influences analogies have had on the field of biology will be examined. Second, current research literature will be drawn upon to further demonstrate the contentious status that the use of analogies in biological instruction has. Finally, analogies used in biology textbooks and biology classrooms will be critically analyzed and a possible solution to the problems they may cause is presented.

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The difference between analogy and other such comparisons like metaphor and simile is largely contextual (scientific versus literary) and depends on the explicitness of the statement (explicit versus implicit) and the purpose of the statement (explanatory, predictive versus expressive, aesthetic) (Duit 1991). Analogies are generally found in scientific contexts and consist of explicit comparisons or mappings between similar features of two otherwise different concepts for an explanatory or predictive purpose. This sometimes includes analogical models, metaphors and similes used in scientific contexts such as Darwin's Tree of Life simile. The familiar concept within an analogy is called the *analog*. This assists in the explanation of the unfamiliar science concept referred to as the *target*. Thus, in the analogy from Darwin's *Origin of Life*, the branching tree is the analog and evolution is the target. The features that are not shared between target and analog are called *unshared attributes* and indicate the *limitations* of an analogy.

Analogies & Their Historical Influence on Biology

An example of an analogy which has influenced biology throughout history has been that between the human being and the world as a whole, in other terms the microcosm and the macrocosm (Arber 1964). Arber claims that although the belief in the microcosmic nature of humankind led to many absurdities, it sometimes opened the way to new and sound conclusions. She claims that Harvey's discovery of the circulation of the blood (1615–19) was based, consciously, upon two Aristotelian tenets—that of the perfection of circular motion, and that of parallelism between the macrocosm and the microcosm.

Darwin's theory of natural selection depends largely upon an analogy, that between the controlled breeding of domestic animals and plants and the whole historic development of the organic world. One of the weaknesses of his theory lies in his failure to recognize the degree of incompleteness of this analogy (Arber 1964). Lamarck, an earlier writer on the subject of evolution, saw an analogy between the individual and the race and concluded that the effects of use and the environment on an individual organism's structure also could be applied to the race (Arber 1964). His theory broke down, because he did not realize that such effects are not passed on from generation to generation. So the analogy on which Lamarck based his work could not be extended as far as he assumed it could.

An example of an analogy that occupied a strategic place in scientific theorizing about human variation in the 19th and 20th centuries is that between females and the races considered to be "lower races" (Stepan 1986). It was claimed that women's low brain weights and deficient brain structures were analogous to those of the "lower races," and their inferior intellectualities explained on this basis. Stepan claims that this analogy led to the suppression of knowledge because scientists unconsciously selected those aspects of reality which were compatible with the analogy. Two examples she cites are that scientists failed to make any correction for women's smaller body weights when arriving at the conclusion of women's inferiority in brain weights, and the Negro race's similarity to apes on the basis of jaw shape was asserted, while the white race's similarity to apes on the basis of thin lips was ignored.

Conversely, Stepan (1986) claims that analogies allow for discovery and can yield new information through empirical research. She believes that without the analogy linking women and race, for example, much of the data on women's bodies, length of limbs, width of pelvis, shape of skull and weight or structure of the brain, would have lost their significance as signs of inferiority and would not have been gathered, recorded and interpreted in the way they were.

Konrad Z. Lorenz delivered a lecture titled, *Analogy as a Source of Knowledge*, in 1973 when he received the Nobel Prize in Physiology or Medicine. According to Lorenz (1974), the study of analogy (he refers to similarities between species caused by parallel adaptation) has been an enormous source of knowledge for evolutionists, embryologists and other kinds of biologists. He refers specifically to the analogy of form due to streamlining, between a swift and a shark for example, and the analogy between the eyes of a vertebrate and a cephalopod. Lorenz describes the value of analogies in his study of behavior and says that:

> Perhaps I should mention here that this procedure has led me to the discovery which I personally consider to be my own most important contribution to science. . . . I could not fail to discover that the very same methods of comparison, the same concepts of analogy and homology, are as applicable to characters of behavior as they are in those of morphology. (p. 231)

In particular, he draws on an analogy between the behavior of human beings and of geese when they fall in love and when they are jealous. He defends accusation of anthropomorphism when describing this behavior of birds and people by saying these terms refer to functionally determined concepts, just as do the terms legs, wings and eyes that have evolved independently in different phyla. He claims that no one uses quotation marks when writing about the eyes or the legs of an insect, and so nor does he when discussing analogous behavior patterns. He believes the value of this analogy is that it demonstrates that such patterns of behavior do, or at least once did, possess a survival value for the species. Additionally, the chances of finding out the survival value of this behavior is vastly increased by finding a pattern in an animal, the geese, on which experiments can more readily be performed.

From these few examples, it can be seen that historically analogies have played an important role in the development of the science of biology. On one hand they have contributed to some great scientific discoveries, on the other hand they have led to scientists being misdirected. By turning to recent research in biology education, it can be demonstrated that a similar situation seems to occur when analogies are used in the biology classroom. In some situations analogies appear to have contributed to increased student conceptual understanding; in others they have been a hindrance rather than a help.

Current Conflicting Research on the Use of Analogies

Duit (1991) gives an overview of the advantages and constraints of analogies as seen from a constructivist position. He says that analogies can be useful pedagogical tools in that they are thought to help students construct new knowledge by linking it with knowledge structures they already have. Additionally, analogies have been shown to be valuable when trying to help students visualize abstract or unobservable phenomenon. A third and sometimes overlooked advantage of teaching with analogies which Duit mentions is the motivational role they can play in the classroom. If the teacher uses an analogy that draws upon the students' real world experience, a sense of intrinsic interest can be generated. If students are able to achieve a higher level of conceptual understanding than usual because of the analogy, this also can result in motivational gain.

Analogies have, however, been referred to as "double edged swords" (Glynn 1989) because although they can be beneficial, they can also be detrimental. Analogies have been shown to be responsible for students having alternative conceptions, ideas different from accepted scientific beliefs. This is believed to be caused by students transferring unique features of the analogical concept to the scientific concept which should not be transferred. Gentner & Gentner (1983), for example, found that people who think of electricity as though it were water import ideas from the domain of flowing fluids when they reason about electricity. Other problems center around students being unfamiliar with the analogous concept, or having a different conception of the analogy compared with the teacher. Analogies also become superfluous if the students already have a good understanding of the science concept.

Much empirical research has found that analogies can contribute to improved understanding of scientific concepts (Dupin & Johsua 1989; Gentner & Gentner 1983; Treagust, Harrison, Venville & Dagner in press). In contrast, other researchers have found analogies used in classrooms have not resulted in greater student understanding and may even have a detrimental effect. We shall explore here examples from the literature that demonstrate this conflicting evidence from studies carried out in the biological science discipline.

Empirical Studies in Biology Education

The results of a study by Bean et al. (1990) indicated that those students who received instruction combining a pictorial analogy comparing a cell to a factory and an analogical study guide displayed significantly better comprehension of this material than did their peers in conditions where the pictorial representation was not included. The authors suggest that the pictorial analogy, which shows how the various parts of a cell are like the parts of a factory, helped the students to learn cell parts and functions.

Newby and Stepich (1991) found that immediate and delayed comprehension of physiological concepts was significantly improved by subjects who received analogies during instruction. Moreover, subjects receiving analogies reported higher perceived levels of lesson enjoyment. The analogies were used to teach 10 advanced physiological concepts; for example, peristalsis was described in terms of an analogy with squeezing ketchup out of a single-serving packet.

In marked contrast to the two studies reported above, Gilbert (1989) concluded that no evidence was found to support the assertion that the general use of analogies is effective in either promoting conceptual retention or in improving students' attitudes. In this situation the analogies were included in text and in questions throughout two 9th and 10th grade general biology units on development and heredity. A literal version of the same text and questions was given to a control group. Examples of the analogies used in this study include comparing the placenta with an electric plug and coin tossing as an extended analogy to explain Mendelian genetics. The results of this study could be interpreted to mean that presenting analogies in a written form is not enough and that the teacher needs to play a more active role in helping the students to use the analogy to learn the scientific concepts.

James (1983) came to conclusions similar to Gilbert's when the analogical practical exercise she used to help her students understand adaptation was not successful. The students performed an activity in which they compared the cooling rates of a flat and a spherical bag of hot water and then answered questions about animals with large ears and their adaptive consequences. The practical exercise was completed by the students at home and they were left to draw the analogical relationship between the activity with plastic bags and animals with large ears by themselves. The conclusion that the analogy did not help the students and that alternative conceptions may even have been generated thus adds to the evidence that students should be given considerable direction when using analogies to learn science. Allowing students to draw their own conclusions about science from analogies may result in misdirection and miscomprehension.

Problems with Analogies Used in Biology Textbooks & Classrooms

Mechanical Clichés

In a comparison of biology and chemistry textbook analogies Thiele et al. (1995) found that biology textbooks included many simple, non-elaborated analogies, for example: *whip-like flagellum, mitochondria are the 'powerhouse' of the cell, ribosomes are protein 'factories', the double helix structure of DNA is like a twisted ladder*, and *enzymes interact with substrates like a lock and key*. The problem with these analogies is that they have become mechanical clichés that biologists, including teachers and textbook authors, use without thinking about the message being conveyed. Some of these analogies might be very useful to students if they were explained in a more detailed manner. For example, the lock and key model for enzyme interaction has the potential to help students understand the specific nature of enzymes. Without further explanation, however, students are left to make their own conclusions about these biological concepts from the analogies. This leaves great potential for alternative conceptions to develop.

Student Unfamiliarity

If students are not familiar with the analog, then the likelihood that they will draw spurious conclusions about the science is greatly increased. In a local biology classroom, we observed a teacher explaining that red blood cells were shaped like a particular brand of candy that has an indent on each side of a disc. It turns out, however, that this brand of candy is no longer round but now has a square shape! Consequently, the use of this analogy may have resulted in this teacher's students being confused about the shape of red blood cells. Thiele et al. (1995) also reported analogies such as the following in Australian high school biology textbooks. "... It is often helpful to think of a community, together with its nonliving surroundings, as a system, just as one can speak of a 'political system' or an 'economic system'" (Morgan 1989, p. 408). Few high school students would be sufficiently familiar with a political system or an economic system to draw relevant similarities with a biological system. This problem arises because it is often the teacher or textbook author who generates the analogy and, subsequently, they neglect to ensure student understanding of the analog.

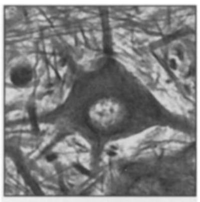
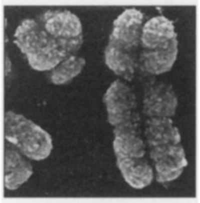
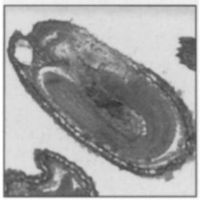
Inconsistencies Between Analog & Target

It is the nature of analogies that the analog and target are not exactly the same. Students may be led to believe that the two concepts share features which in fact they do not. For this reason it seems important that teachers explicitly map the shared attributes and delineate the limitations of analogies. It also may be advantageous if students are given some kind of training on how to use analogies when learning science (Venville et al. 1994).

Solutions: How Should Teachers Use Analogies in Biology?

It seems from the discussion above that analogies are certainly a contentious issue in biology education. They may well be able to improve student understanding of some biological concepts; however, it is clear that using analogies can create problems. Teachers have often reported that the analogies they use are useful and have encouraged other teachers to use similar techniques (Biermann 1988; Kangas 1988; McNevin 1992; Oakley 1994; Stencel & Barkoff 1993). How can teachers take advantage of these and other analogies as a pedagogical tool while keeping the misdirection and miscomprehension that may result from their use to a minimum?

Approaches for the use of analogies in science teaching have been developed (Clement 1987; Dupin & Johsua 1989; Gentner & Gentner 1983; Glynn 1991; Zeitoun 1984). One of the most useful of these models in terms of the classroom situation is Glynn's Teach-

FOCUS	
CONCEPT	Is it difficult, unfamiliar or abstract?
STUDENTS	What ideas do the students already have about the concept?
ANALOG	Is it something your students are familiar with?
ACTION	
LIKES	Discuss the features of the analog and the science concept. Draw similarities between them.
UNLIKES	Discuss where the analog is unlike the science concept.
REFLECTION	
CONCLUSION	Was the analogy clear and uneful, or confusing?
IMPROVEMENTS	Refocus as above in light of outcomes.

Figure 1. The FAR Guide for teaching and learning science with analogies (Treagust et al. 1994).

ing-With-Analogies (TWA) Model. This model was developed from the examination of exemplary textbook analogies, and key operations performed by the authors were incorporated into a six-step model which was designed as a guide for teachers and authors of science textbooks. Subsequently we have modified the model and have provided inservice education for teachers using the Teaching-With-Analogies Model. However, the exemplary teachers with whom we were working on a series of collaborative exercises adapted and modified this model to suit the classroom situation. Analysis of their teaching resulted in the development of a three-phase model which appears to be more efficient and effective. The three phases of the model, *Focus*, *Action* and *Reflection*, are used to form the acronym FAR and we have developed 'The FAR Guide for teaching and learning science with analogies' (Treagust et al. 1994). Because of the inductive manner in which the FAR Guide has evolved from exemplary science teachers' practice, this model probably has the greatest potential for improving science teachers' use of analogies.

The FAR Guide (see Figure 1) was developed within a constructivist theoretical framework with paricular emphasis on the use of analogies to engender conceptual change. It aims to maximize the benefits and minimize the constraints of analogies when used to teach science. The guidelines are practical and clearly address the problems associated with analogies which have been described above. The first phase of the FAR Guide is *Focus*. Teachers are encouraged to focus on the science content to ascertain why it is difficult, focus on the analog to ensure it is familiar to the students, and focus on the students themselves to consider the ideas they already have about the science concept. The second phase of the FAR Guide is *Action*. Here it is considered imperative that the teacher and students discuss both the similarities and differences between the science concept and the analog so that the limitations of the analogy are clearly delineated. The final phase of the FAR Guide is to *Reflect* on the analogy, to draw conclusions and decide whether it was clear and useful or confusing, and to improve the analogy in light of this reflection.

Used in an optimal manner, analogies can be a useful strategy for developing common knowledge and shared meaning between teacher and student. If science teachers were able to follow the steps of the FAR Guide, then the result would be a cyclic process of improvement and modification of the analogies they use. The most important potential benefit would be that science teachers would consider each analogy and its possible pitfalls before they used them. Feedback from science teachers who have participated in workshops using the FAR Guide indicate that the approach has enabled teachers to improve their analogical instruction as part of their teaching repertoire (Treagust, Venville & Harrison 1994). A formal evaluation of the FAR Guide is currently in progress.

Conclusion

Analogies are an integral part of biology and biological education. It has been argued, however, that analogies have benefits and they have constraints, therefore, their use in the classroom is a contentious issue. At best, biology teachers can hope to use analogies in an optimal way. One model that may be of use to biology teachers who aspire to do this is the FAR Guide for teaching and learning science with analogies. Teachers should be encouraged to adopt this guide and exploit the potential benefits of analogies used in biology education.

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