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Recent research literature has highlighted the interest of both teachers and researchers in using analogies to aid students' conceptual understanding. This appears to be especially relevant in secondary chemistry education due to the many abstract concepts that are included in the curricula. This paper reviews recent literature and considers analogy examples from textbooks to identify the advantages and constraints of using analogies to aid the teaching of abstract concepts in secondary chemistry. Particular constraints include: (1) incorrect transfer of attributes; (2) analog unfamiliarity; and (3) stages of cognitive development. (Contains 16 references.) (Author/MDH)

USING ANALOGIES IN SECONDARY CHEMISTRY TEACHING

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ABSTRACT

Recent research literature has highlighted the interest of both teachers and researchers in using analogies to aid students' conceptual understanding. This appears to be especially relevant in secondary chemistry education due to the many abstract concepts that are included in the curricula. This paper reviews recent literature and considers analogy examples from textbooks to identify the advantages and constraints of using analogies to aid the teaching of abstract concepts in secondary chemistry.

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INTRODUCTION

Have you ever experienced frustration when attempting to explain abstract chemistry concepts to a class, small group, or an individual? Those teachers who sometimes feel this way are probably not in the minority. To assist in explaining abstract chemical concepts, those teachers who strive to help their students achieve conceptual understanding, rather than algorithmic understanding, will often employ teaching tools such as analogies or models. These tools can allow the new material to be more easily assimilated with the students' prior knowledge enabling those who do not readily think in abstract terms to develop an understanding of the concept.

However, teachers occasionally discover that students take the analogy too far and are unable to separate it from the topic being learned. Other students only remember the analogy and not the topic under study whilst yet others focus upon extraneous aspects of the analogy to form spurious conclusions relating to the topic. This paper considers the advantages and the constraints of using analogies in chemistry instruction by examining recent research literature and chemistry textbooks.

THE POTENTIAL OF ANALOGIES IN TEACHING

The use of analogies is well linked to science in both historic and contemporary settings. Well renowned theorists such as Maxwell, Rutherford, and Einstein are reported to have used analogical reasoning as a tool to aid problem solving (Curtis & Reigeluth, 1984). Further, it has been proposed that analogies are traditionally used both in explaining science and in the processes of science (Shapiro, 1985). However, little has been determined from empirical studies about the actual learning processes that are associated with analogy assisted instruction as most of the studies only measured the students' recall of learned materials. It is also not well known if analogies assist students to attain a level of conceptual understanding or whether students view the analogy as only another algorithmic method to obtain the correct answer.

Analogies are believed to work by assisting in the creation of new knowledge that is embedded in a particular idea or concept. When new information is being taught, it can be introduced more easily when it is related to, or compared with, an existing knowledge structure found in a suitable analogy. Hence, analogies can help to arrange the existing memory and, therefore, assist in the preparation of the existing knowledge structures for the new information (Shapiro, 1985).

ANALOGIES AND HOW THEY WORK

There is a need to clearly define what an analogy is so that it is not confused with illustrations and examples. Glynn et al. (1989) provide a useful working definition:

> An analogy is a correspondence in some respects between concepts, principles, or formulas otherwise dissimilar. More precisely, it is a mapping between similar features of those concepts, principles, and formulas. (p. 383)

In its most simple form, an analogous relationship in mathematics can be expressed to show concepts in the manner A:B::C:D. For example 4:16::3:_, where the relationship between A and B provides indication as to the solution of D, given C. In a literary sense, an analogous relationship may be expressed as follows: Einstein : Relativity :: Darwin : ____.

The analogy requires the selection of an analog to assist in the explanation of the content specific target (or topic). The target and analog share attributes that allow for a relationship to be identified. The use of these specific terms varies amongst researchers. A representation of the analogous relationship is shown in Figure 1.

Insert Figure 1 about here

An analogy that is often used when students are studying the topic of catalysis is that of a train passing through a tunnel rather than over a hill (Thiele, 1990a). In this analogy, the target concept is the ability of a catalyst to provide an alternative reaction mechanism (path) having a lower activation energy. The analog is the mental imagery, created in the minds of the students, of the train passing through the tunnel. There are several readily observable attributes which are shared between the analog and the target in this analogy. Firstly, the train will not always have sufficient energy to get over the hill if the tunnel is not used. At a particular temperature, only a small number of collisions are successful unless a catalyst is introduced. Secondly, if a train were able to traverse the hill route, the end result of the journey is the same regardless of which path is chosen - indicating that there will be no effect on the enthalpy change of a reaction. This comparison of shared attributes is known as mapping. It is also true that there are attributes of both the train/tunnel image, and the reaction processes, that are not shared. For example, the train is able to continually convert its energy source during the uphill climb, whereas a reacting system relies upon the total kinetic energy of the system at some instant prior to collision.

When mapping shared attributes, a relationship between the analog and the target might be one of either structure or function. In a structural analogy, some physical attribute of the analog illustrates a physical attribute of the target. In the train analogy, the hill shape is analogous to the potential energy - time graph of a reacting system (but not analogous to any physical characteristic of the system itself). In a functional analogy, the behavior of the analog illustrates that of the target. The train analogy adds visual reinforcement of the alternative route taken by a reacting system in the presence of a catalyst. It should be noted that an analog may share both structural and functional attributes with the target simultaneously. It must also be considered that the analog and the target will have many attributes that are not shared.

Discussions relating to the use of analogies in chemistry education found in educational literature have indicated the confusion that is occasionally shown when differentiating analogies from illustrations and examples. This is highlighted in several articles, for example, Remington (1980), which present different methods of illustrating the magnitude of Avogadro's number. As Avogadro's number is just a number and need not be subject specific, illustrations showing how thick a layer of Avogadro's number of marbles would coat the earth do not ideally match the definition of an analogy presented by Glynn et al. (1989) but are better considered as illustrations or perhaps examples. However, a use more aligned with the definition above by Glynn et al. (1989) for an analogy in the mole topic is found in Garnett (1985):

> Just as it is convenient to group eggs into cartons of a dozen or sheets of paper into reams (500 sheets), chemists measure the amount of any substance in terms of moles. (p. 41)

In this analogy, the target concept is the mole while the analog is dozens and reams. The attribute shared by both the target and the analog is the convenient grouping of substance.

Science education researchers have investigated the relationships of analogy effectiveness to Piagetian stages of cognitive development. The literature reports that analogies are employed most often when the target has a formal nature and the analog is at the concrete stage because much science content is beyond the limits of our own senses. For example, chemistry requires the examination of the submicroscopic realm where direct sensory experience is not possible. Gabel and Sherwood (1980) reported that chemistry instruction incorporating analogies may have been effective for students of lower formal reasoning ability but not especially useful for the more academically capable students. Students operating at the concrete or transitional stages of development require assistance if abstract or formal cognition is to occur.

Duit (1990) proposes that analogies are most used when the target domain is most difficult to understand. The presentation of a concrete analog in this situation facilitates understanding of the abstract concept by pointing to the similarities between objects or events in the students' world and the phenomenon under discussion. Other researchers (Curtis & Reigeluth, 1984; Shapiro 1985) also consider that the use of an analogy initiates important visualization processes in the learners' minds and hence allows for more efficient learning.

DIFFERENT TYPES OF ANALOGIES

The literature highlights a range of types of analogies and structures for analogies which include personal analogies and pictorial analogies (Duit, 1990). It is also evident that the presentation by the classroom teacher has a considerable influence upon the mode of operation of an analogy. For example, some teachers will involve students in their own analogy formulation, others will guide the students in the use of a presented analogy, whilst other methods require only passive participation by the student.

Personal Analogies

Personal analogies generally take two forms -- one in which the learners take an active physical role and the other in which they take an active mental role.

Students may be physically active by being involved in role playing where they position themselves in the classroom according to gender. This positioning of students by gender is analogous to the positioning of ions in a crystalline lattice according to opposite ionic charges.

The following is an example of how a teacher could encourage a mentally active role for the student in a personal analogy:

> Consider yourself aboard one of the several decks of a large ocean liner about to depart the quay on a long cruise. Your friend is standing upon the quay to bid you *bon voyage*. Your friend can only see you when you appear on one of the decks -- you are not seen between decks.

This is an example of an analog used to discuss the arrangement of electrons in specific shells or orbits. Its presentation here requires active mental participation. The same analog has been presented also in pictorial format in Hunter et al. (1981), as shown in Figure 2.

Insert Figure 2 about here

Marshall (1984) provides several personal analogies that relate chemical principles to human behaviour, money or to food. In her experience, these analogs are readily accepted by the students and they are analog fields with which we can confidently expect that the student is familiar. One personal analogy, recommended by Marshall for the teaching of stoichiometric excess and limiting reagents, requires the students to imagine that they are making chocolate snowballs using four ingredients in a fixed proportion. The number of snowballs that may be produced depend upon the limiting ingredient. Marshall suggests that this type of analogy causes better learning of concepts and that the approach is more enjoyable although she cautions that personal analogies can cause students to give intuitive feeling to inanimate objects and concepts.

Pictorial Analogies

Given that one of the main emphases of analogy usage in chemistry education is to make abstract concepts more easily grasped by the lower achieving student or by the concrete or transitional thinker, the use of a diagram or picture to present the analog, as illustrated in Figures 2-4, is considered to be most advantageous. In pictorial analogies, some diagrammatic illustration (or occasionally a photograph) of a real life (student world) situation is presented as part of, or all of, the analog. A pictorial analogy allows for the simple introduction of analog attributes to the learner avoiding the possibility that the student will mentally create attributes not present and also avoiding the need for lengthy prose to describe the analog. Most pictorial analogies are accompanied by some verbal explanation and hence should technically be referred to as pictorial-verbal analogies. A significant advantage of using a pictorial presentational format for the analog is that it should increase the likelihood that the analog is familiar to the learner (Duit, 1990).

Insert Figure 3 about here

Researchers agree that the visualization process is very important in the learning of concepts. Shapiro (1985) suggests that the pictures prompt a visualization process to aid understanding. In an analysis of 216 analogies found in science textbooks for secondary students, Curtis and Reigeluth (1984) found that chemistry textbooks contained the highest percentage of pictorial- verbal analogies (29%) compared to the total science average of only 16%. Thiele (1990b) examined ten textbooks available to Australian secondary chemistry students and found that 71% of the analogies in the content areas of energy effects, reaction rates, and chemical equilibrium were presented in a pictorial format.

THE CONSTRAINTS OF ANALOGIES

Despite the advantages and usefulness of analogies as previously outlined, the use of this teaching tool can cause incorrect or impaired learning due to some fundamental constraints related to the analog - target relationship. Remington (1980) introduces his article about an extended analogy for the teaching of chemical formulae by stating:

> Analogies can be subtle - but in teaching most tend to be more like bulldozers: an unskilled operator can create havoc with one, whereas a skilled operator can accomplish much useful work in a short time. No analogy fits perfectly with its targeted concept. The teacher's skill comes in demonstrating how the two compare and how they contrast. (p. 35)

Incorrect Transfer of Attributes

The nature of the analog is that it has some shared attribute(s) with the target. Licata (1988) considers that the unshared attributes are as instructive to the students as are the shared attributes. A good analogy, skilfully used, may share only one attribute - others may share many attributes. None share all as, if they did, the analogy would become an example by definition (Glynn et al., 1989). These attributes that are not shared are often a cause of misunderstanding for the learners if they attempt to transfer them from the analog to the target.

Insert Figure 4 about here

Both Licata (1988) and Webb (1985) suggest that discussion should take place during instruction to assist in the delineation of boundaries and to aid concept refinement. Allowing for student involvement at this level also provides feedback to the instructor if incorrect attribute transfer has occurred. Teachers should not assume that the students are capable of effecting correct analogical transfer but, rather, should provide explicit instruction on how to use analogies and provide opportunity for considerable classroom discussion on the subject.

As analogies and targets have only a few (perhaps just one) shared attributes, it is evident that all of the attributes of the target will rarely be covered by one analogy alone. Thus, it may be useful to use several analogies to cover any one target. For example, the analogy of a pole vaulter approaching the bar for a vault has been used to illustrate a reaction proceeding towards the transition state and to show the energy required by the reacting system. When introducing catalysis, some will extend the analogy and lower the bar (Parry et al., 1976, p. 239) but this can lead to the incorrect assumption by the students that both the catalyzed and uncatalyzed reaction follow the same reaction path and that the catalyst lowers the activation energy rather than providing an alternative route that has a lower activation energy. It would be better to present a different height bar next to the original bar to indicate that the catalyst provides an alternative route that is more energetically favourable.

Analog Unfamiliarity

A second constraint of the use of analogies is the possible unfamiliarity of the learner with the analog selected. Empirical studies on the use of analogical reasoning in chemistry instruction , for example of analog unfamiliarity. Gabel and Sherwood (1980), have been hindered by this problem. The finding that a significant proportion of students did not understand the analogy shows clearly the need for caution in teaching with this method and in evaluating analogies designed to improve student understanding of chemistry concepts.

Stages of Cognitive Development

A third area of constraint with analogy usage relates to the Piagetian stages of cognitive development. Whilst there is general agreement that analogies can assist students who primarily function at lower cognitive stages, if these students lack visual imagery, analogical reasoning, or correlational reasoning, then the use of analogies is still believed to be limited (Gabel & Sherwood, 1980). In addition to this, those students already functioning at a formal operational level could be conversant enough with the target and the inclusion of an analogy might add unnecessary information loads and may also result in new misconceptions being formed by the students. For these reasons, some instructors choose not to use analogies at all and thereby avoid these problems while, at the same time, they forsake the advantages of analogy use.

SUMMARY

The historical use of analogies has been well documented in the literature and recent attempts to empirically demonstrate their effectiveness have produced mixed results. On the one hand, analogies are believed to help students attain abstract concepts by rearranging the existing cognitive structures to facilitate the assimilation of new information. However, on the other hand, researchers attempting to demonstrate the links between problem solving ability and analogy use have indicated frustration at the small number of students who were capable of understanding the analog itself and of making the analogical transfer from the analog to the target.

Several different types of analogies have been discussed and these allow for a range of teacher style, student ability, and content under study. Emphasis from the literature indicates the importance of the teacher in the use of analogies. It is seen as the teachers' role to aid the student in the process of analogical transfer rather than just presenting the analog and the target and expecting the student to make the correct connections. However, recent research (Treagust, Duit, Joslin & Lindauer, 1989) has shown that science teachers do not readily use analogies as part of their regular teaching routines. Hence, if analogies are to be more effectively used, it may be necessary to provide inservice opportunities to enable analogies to become a part of regular teaching repertoires.

Whilst there is general agreement amongst researchers as to the usefulness of analogies as a teaching tool, there is some doubt as to whether students actually do use them to aid understanding of concepts or whether they just provide the service of a further algorithm to facilitate rote learning. This area is the subject of ongoing research.

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ANALOGICAL RELATIONSHIP

ANALOG ....compared with ....TARGET

Attribute ... Attribute

1..............compared with...............1

2..............compared with...............2

3..............compared with...............3

n..............compared with...............n

Figure 1. Analogical relationship between analog and target illustrating the sharing of attributes (Adapted from Glynn et al., 1989, p. 384).

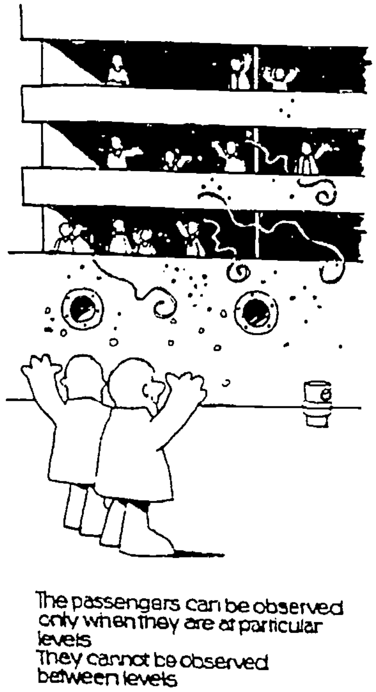

Figure 2. A pictorial example of a personal analogy taken from Chemical Science (p. 144) by R. J. Hunter, P. G. Simpson, D. R. Stranks, 1981, Marrickville, NSW: Science Press. Copyright 1981 by Science Press. Reprinted by permission.

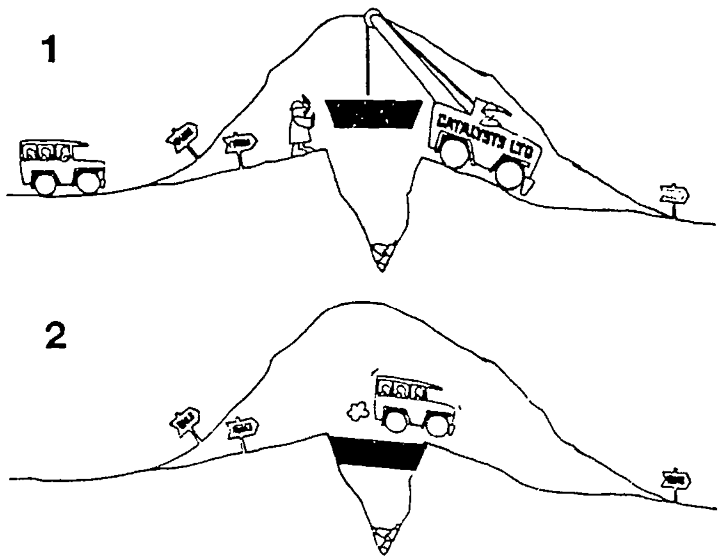

Figure 3. An example of a pictorial analogy taken from Chemical Science (p. 257) by R. J. Hunter, P. G. Simpson, D. R. Stranks, 1981, Marrickville, NSW: Science Press. Copyright 1981 by Science Press. Reprinted by permission.

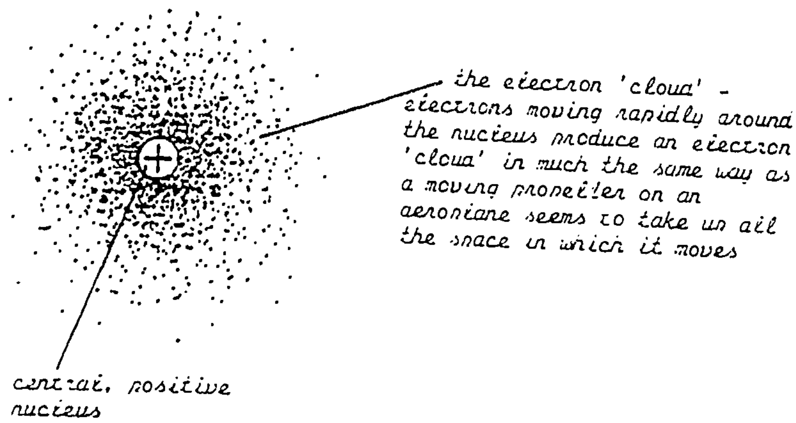

Figure 4. A pictorial analogy taken from A Guide to H.S.C. Chemistry (p. 1) by P. Lewis and R. Slade, 1981, Melbourne, VIC: Longman Cheshire Pty Limited. Copyright 1981 by Longman Cheshire Pty Limited. Reprinted by permission.