Use of Analogy in Teaching The ParticULate Theory of Matter

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Introduction

Over the past two decades, there has been considerable interest among science educators concerning the use of analogies in teaching science concepts, theories and models (Treagust et al. 1989; Duit 1991; Clement 1993).

In the history of science, analogies have been tools of discovery and invention. For instance, Kepler developed his concepts of planetary motion from the workings of a clock (Bronowski 1973) and Huygens utilised movement of water waves to conceptualise the nature of light (Duit 1991).

Meaning of Analogy

As suggested by Duit (1991), the term "analogy" refers to comparisons of structures between two domains; a domain familiar or known to the learner and a new domain. Treagust et al. (1992) further suggest that "an analogy is a relation between parts of the structures of two conceptual domains and may be viewed as a comparison statement on the grounds that these structures bear some resemblance to one another".

In the context of science teaching, Treagust (1993) offers an operational definition of analogy as "a process of identifying similarities between two concepts. One concept, which is familiar, is referred to as the analog, and the other concept, which is unfamiliar, is called the target".

Advantages of Analogies

The following are some advantages of analogies:

- They are valuable tools in conceptual change learning.
- They provide visualisation and understanding of the abstract by pointing to similarities in the real world.
- They may incite pupils' interest and hence have a motivational effect.
- They force the teacher to take into consideration pupils' prior knowledge and may reveal misconceptions in previously taught topics.

PITFALLS IN USING ANALOGIES AND HOW TO AVOID THEM

However, an analogy is a double-edged sword in that uncritical use of it may lead to misconceptions. This is because there is no such thing as a perfect analogy, that is, it is almost always impossible to have a perfect one-to-one fit between the analog and the target. Some pupils may only remember the analog and not the target, while others may focus on irrelevant aspects of the analog to form incorrect ideas about the target (Cosgrove and Osborne 1985; Glynn 1989; Duit 1991).

One way of addressing problems associated with uncritical use of analogies is to adopt the six-step approach suggested by Harrison and Treagust (1994) which is based on a modification of Glynn's (1991) TWA (Teaching-With-Analogy) model.

Although the six steps below are numbered from 1 to 6, the numbering does not necessarily reflect the order in which the steps are to be carried out. Each step is important but the order in which the steps are employed depends on the individual teacher's style, the particular target concept, the analogy being used and the lesson structure that the teacher has in mind. The six steps are as follows:

1. Introduce the target concept to be learned.
2. Cue the pupils' memory of the analog.
3. Identify the relevant features of the analog.
4. Map out the similarities between the analog and the target.
5. Indicate where the analogy breaks down.

6. Draw conclusions about the target concept.

In the next section, an illustration of the use of this six-step approach in teaching the particulate theory of matter is given.

USING ANALOGY TO TEACH THE PARTICULATE THEORY OF MATTER

This section illustrates the use of six-step approach in using analogy to teach the particulate theory of matter, which is crucial to understanding the way in which particles are related in the three states of matter; namely, the solid, liquid and gaseous states.

Thus, if one were to adopt the above six-step approach, one could begin by introducing the relevant features of the particulate theory. This will include the following ideas concerning the target concept:

- Matter can exist in three physical states; namely, solid, liquid and gaseous.
- Matter is made up of particles which are in constant motion, resulting in their possession of kinetic energy which tends to keep them well spaced out in any substance.
- Solids have fixed shapes and volumes because particles in solids vibrate about fixed positions.
- Liquids have fixed volumes but no fixed shapes because the particles in liquids are able to slide over each other.
- In solids and liquids, particles are close enough to each other for the attractive forces between them to be important.
- In gases, there are no significant forces of attraction among the particles comprising the gas. This means that they are moving independently of each other in all directions and at great speeds. Because of their great speeds, a gas will rapidly spread out to fill any container into which it is placed and cannot be said to have a shape of its own.

Having introduced the target concept to be learned, the next step could involve cueing pupils' memory of the analog. The teacher could say, *"Let's use this class as an analogy to make the three states of matter more real to us. Right now, as I am talking to you and explaining the particulate theory of matter, each of you are expected to stay at your own seats. You could be nodding your heads, moving your pens, taking notes, raising your hand and so forth, but you are not allowed to leave your seats. However, in the next half of this lesson, when you are doing your practical work, you are free to move around this laboratory, but none of you can leave this room except under special circumstances. When the bell rings at the end of the school day, you are completely free to move. In other words, you would be leaving this room and heading in different directions for home."*

The next step could then involve identifying relevant features of the analog. Here, the teacher could hold before the pupils, a piece of ice cube and say,

"This ice cube is made up of tiny particles called molecules. We are going to imagine that each pupil in this class is like a molecule of water in this ice cube. Remember, however, that the number of molecules in even a tiny piece of ice will contain many times more molecules than there are pupils in this class." (Step 5 - Here the teacher gives an instance of where the analogy breaks down.)

Having identified relevant features of the analog, the teacher could then proceed to map out the similarities between the analog and the target. The teacher could say,

"Solids have fixed shapes and volumes. This led scientists to think that each particle (molecule) has a fixed position. Thus, the particles in the solid state would be similar to a class of pupils like you are right now – sitting in your fixed positions, listening to me and taking notes. Each pupil has a fixed position just like each molecule in water has a fixed position. Each molecule of water can vibrate about fixed positions but cannot move from one position to another. Similarly, you are not allowed to get up from your seats but you can move your arms, legs, necks and talk. In other words, you are like particles in the solid state vibrating about fixed positions."

"When ice absorbs heat, it melts to form liquid water. Liquids have fixed volumes and they take the shapes of the container they are in (i.e. liquids have no fixed shapes) because the particles in the liquid are free to move within a fixed volume. This is somewhat similar to this class when each of you is carrying out practical work. In this 'liquid' state, each of you is free to move anywhere within this room

('the container') but you cannot leave the room except under special circumstances."

"When liquid water absorbs heat, it evaporates to form water vapour, a gas. Gases have neither fixed volume nor shape. They completely fill their container and spread out to all parts of the enclosing vessel. This is like each of you at the end of the school day when you are no longer held close to each other (no attractive forces whatsoever between the particles in a gas) and you spread randomly throughout the container (in this case, the whole of Singapore and perhaps, even Johore Bahru)."

"Now, coming back to the case of the liquid state. When each of you is carrying out the practical work, think about the special circumstances such as when I send some of you on different errands. In this case, the pupils who leave the room are like molecules of water which occasionally gain sufficient energy to evaporate and leave the liquid surface. When pupils who are sent out on errands return to the class, they are like molecules which evaporate and condense back into liquid water."

Having mapped out the similarities between the analog and the target, the teacher could proceed to address the limitations of the analogy or to indicate where the analogy breaks down. Such limitations could include the following:

- Molecules are very, very small and there would be many more water molecules in the ice cube than there are people on our planet.

- Particles in the solid and liquid states are closely packed, whereas pupils in class are not.

- Particles in the solid state vibrate continuously but pupils' movements are variable.

- Particles cannot think and hence, have no control over their movements whereas pupils do think and have control over their own movements.

- In the "solid" and "liquid" cases, the teacher in the class who is in control cannot be compared to anything in the target.

- In the gaseous state, particles have high instantaneous velocities and are involved in collisions with other gas particles or with the walls of their container. Pupils after school are not likely to have high instantaneous velocities and are not likely to collide with each other (not even when they are playing vigorous games such as soccer, basketball or netball after school).

The final step involved would be for the teacher to draw conclusions about the target concept. Here, the teacher could point out that, whilst it is impossible to visualise the behaviour of particles in the three different states, the analogy drawn on the movement of pupils in the class demonstrates that particles in the solid state vibrate about fixed positions resulting in fixed shape and volume; particles in the liquid state are mobile within a pre-determined volume resulting in fixed volume but variable shape; and particles in the gaseous state move independently of each other, resulting in variable volume and shape.

Conclusion

Given the abstract nature of many scientific concepts, the above modified Teaching-With-Analogy approach should be included as part of the repertoire of approaches held by a Science teacher. The use of analogies in teaching is in line with well-known theories of learning such as Ausubel's which highlight the importance of prior knowledge of the learner and the importance of providing linkages between prior knowledge of the learner and the new knowledge to be acquired.

The systematic use of the approach which ensures congruence between the way the teacher and the pupils visualise the analog and the target should address concerns about pupils' misconceptions through lack of good understanding of the analogy and through over-extension of irrelevant features of the analog to the target.

REFERENCES

Bronowski, J. (1973). *The Ascent of Man.* London: British broadcasting corporation.

Clement, J. (1993). Using bridging analogies and anchoring intuitions to deal with students' preconceptions in physics. *Journal of Research in Science Teaching,* 30 (10): 1241-1257.

Cosgrove, M. & Osborne, R. (1985). A teaching sequence on electric current. In R. Osborne & P. Freyberg (eds.), *Learning in Science: The Implications of Children's Science.* Auckland: Heinemann.

Duit, R. (1991). On the role of analogies, similes and metaphors in learning science. *Science Education,* 75: 649-672.

Glynn, S. (1989). The teaching with analogies (TWA) model: Explaining concepts in expository texts. In K.D. Muth (ed.), *Children's Comprehension of Narrative and Expository Text: Research into Practice.* Newark DE: International Reading Association.

Glynn, S. (1991). Explaining science concepts: A teaching-with-analogies model. In S. Glynn, R. Yeany & B. Britton (eds.) *The Psychology of Learning Science.* Hillsdale, N.J.: Erlbaum Associates.

Harrision, A. & Treagust, D. (1994). The three states of matter are like students at school. *Australian Science Teachers Journal,* 40 (2): 20-23.

Treagust, D., Duit, R., Lindauer, I. & Joslin, P. (1989). Teachers' use of analogies in their regular routines. *Research in Science Education,* 19: 291-299.

Treagust, D., Duit, R., Joslin, P. & Lindauer, I. (1992). Science teachers' use of analogies: Observations from classroom practice. *International Journal of Science Education,* 14(4): 413-422.

Treagust, D. (1993). The evolution of an approach for using analogies in teaching & learning science. *Research in Science Education,* 23: 293-301.