Analogy is a specific form of similarity, but it is often quite vague (24). Few of the analogies used in science are as straightforward as the simplest analogy (such as “an arm is to a leg as a hand is to a foot”), but Gentner’s (8) structure-mapping theory is helpful in understanding the nature of more complex analogies and in clarifying specific examples. According to this model, an analogy is a mapping of knowledge from one domain (the base) onto another (the target). The objects that make up the base have specific attributes and are linked by a system of relations, which also holds in the target (Fig. 1). The strength of an analogy depends on the interdomain consistency of the relations rather than the attributes (8,
A Personal View

ANALOGIES

Fig. 1. The similarity space indicating the sharing of relations and attributes between the base and target domains. If the base and target share attributes but not relations, their similarity is superficial; if they share both relations and attributes, they are literally similar (or perhaps even identical). In an analogy, the relations are shared between the base and target, but the attributes are not. [From Gentner (7).]

24). In those cases where the base and target have common attributes [consider an analogy between (hand, glove) and (foot, shoe)] and common relations (such as “is covered by,” so a hand is covered by a glove and a foot is covered by a shoe), there is similarity (Fig. 1). Where base and target have common attributes but do not share relations, there is just a superficial similarity (consider the relation “is protected by,” so a foot is protected by a shoe, but a glove provides little protection for a hand). Analogy arises where the base and target do not have common attributes [like (hand, glove) and (key, lock)] but do share relations [the relation “fits perfectly” can be applied to both (hand, glove) and (key, lock)]. In most analogies, some relations do apply to both the base and target, but others do not. Useful analogies have larger numbers of shared relations and small numbers of common attributes (Fig. 1).

For example, water flowing through a pipe is often used as an analogy for blood flowing in a blood vessel (25). Assuming that the comparison is taken beyond the “a blood vessel is a pipe” metaphor, the objects in the base are (water, pipe), and a relation between them might be the flow, which depends on both the viscosity of the water and the diameter of the pipe (which are attributes of the corresponding objects). The objects in the target are (blood, blood vessel), and, again, the flow of blood depends on the viscosity of blood and the diameter of the vessel. However, like all analogies, the (water, pipe) → (blood, blood vessel) analogy does not completely map all of the relevant relations of the target concept. For example, elasticity is an important attribute of blood vessels but not necessarily of the sorts of pipe a student might visualize (28), leading to misconceptions about the behavior of blood vessels. Similarly, blood and water differ in their mechanical properties (water is a Newtonian fluid, whereas blood is not), which means that they respond differently to changes in conditions, which is important for blood as it passes through capillaries, for example.

Many important physiological analogies are related to the suggestion that the human body is analogous to a machine, usually attributed to Descartes in Traité de l’Homme, although mechanical analogies for physiological processes were used before its publication in 1633. The machine analogy is often applied to areas ranging from enzyme catalysis (1) and cell biology (2) to the global ecosystem (17). While the machine analogy is valuable, it can lead to confusion. For example, the heart is often compared with a pair of linked pumps, but a student might have no conception of how a pump works or, perhaps worse, might visualize any one of many different sorts of pump. Even if the heart/pump analogy can be well defined and all the features of the heart accommodated, is the same sort of pump to be envisaged when considering the “Na⁺-K⁺ pump” or “Ca²⁺ pump?”

Teach Students About Analogy

While analogies are frequently encountered in daily life (13), there is no compelling justification for assuming that students will necessarily understand how they work (16), and so this should be made clear. Even if students are familiar with metaphor and analogy, they may not connect this insight with the examples they subsequently meet in the science classroom. It is, therefore, only reasonable to teach students about the nature of analogy. This has been an effective strategy in various contexts (9, 12, 18, 29).

At least three questions are prompted by the intention to teach about analogy: 1) what is an analogy, 2) what are analogies used for (and what are the advantages of this), and 3) what are the limitations of analogy? Defining analogy for students need not involve explicitly teaching the Gentner model or an alternative, but it is important to distinguish the concepts of relation and attribute. For example, Gionfriddo (9) described a simple model involving red and green apples and a green pear, in which she asked students to decide how the fruits could be grouped (by color or type of fruit, for example). The role of analogy in making a complex concept more accessible and the limitations of analogy in this respect can be taught by example.

Explain Analogies Clearly: Mappings, Significance(s), and Limitations

A significant risk of the use of analogy is that the student is left with ill-defined ideas unless the teacher explains the analogy. While it is clearly the case that analogy can be vague, the “vagueness of analogy need not diminish its interest and usefulness” (24). Nevertheless, it is inevitable that an analogy will fail, if only because, were all the relations in the target concept to map to the base concept, then there would simple identity (Fig. 1). Polya’s dictum (24) that if we are to make analogies respectable, we should clarify them is apposite.

Clarification of an analogy involves clearly comparing the base and target but, more importantly, demonstrating the relations that they share and those that are not shared. In the (water, pipe) → (blood, blood vessel) example, the shared relations and attributes are easily stated (as they are above), but the limitations of the analogy (such as those previously outlined) are critical to a sophisticated appreciation of the flow of blood through a vessel. In this example, as in many others, analyzing the limitations of the analogy enables one to teach more effectively. Moreover, the analysis of such limitations teaches students about the nature of science, not only about the example being considered. Arguably, this latter benefit is fundamentally important: analogies are much more than just teaching tools; they are also tools for developing ideas, insights, and

hypotheses. The exploration of an analogy compared with the results of experimental exploration of the phenomenon it models helps to identify misconceptions. Analogy is a tool of science, and its use is, in effect, a model of professional behavior.

Many concepts can be expressed mathematically, for example, blood flow through a blood vessel can be expressed in mathematical form (25). The equations constituting such a mathematical model are themselves an analogy of the phenomenon to which they relate. The mathematical variables represent particular real-world observables, and the relationships between those observables are expressed by the mathematical functions in the equations. For example, returning to the (water, pipe) (blood, blood vessel) analogy, a standard mathematical application of Poiseuille’s law relates the pressure drop (Δp) to the volume flow rate (Q) using the diameter (D) and length (L) of the vessel and the viscosity (η) of the blood (25). In this case, the analogy embodied in the mathematical model could be written as (Δp, Q, D, L, η) (pressure drop, flow rate, diameter, length, viscosity). As with nonmathematical analogies, a vital function of a mathematical model is testing an ability to predict real-world events and to identify misconceptions.

Develop Good Analogies Carefully

Good analogies are simple, easy to remember, and based on familiar analog concepts (23). The (water, pipe) (blood, blood vessel) example satisfies these requirements, but even such good analogies have limitations, as outlined above. Orgill and Bodner (23) recommended that analogies should be used when a difficult or challenging concept that cannot be visualized is introduced. However, they warn against the use of analogy when the target concept is overwhelming or has to be memorized. To be most effective, the elements of an analogy must be made clear and its limitations need to be explained.

Conclusions

Much of the education literature concerning analogy relates to events in pretertiary classrooms, where the students may not be sophisticated enough to appreciate the nuances of scientific thought (29), but in tertiary classrooms, students need to understand the nature of science, the modes of argument, and model construction. If we give in to Simanek’s (27) view, students may learn the “facts” but not the “thought” that led to them. Arguably, the thought is more significant than the facts, which can be learned and are rapidly forgotten (4). So, students should be taught about argument, analogy, induction, and the other skills of logic that are commonly used in science. In other words, we should teach not only science but also about science.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

REFERENCES