TEACHING WITH ANALOGIES: EXAMPLES OF A SELF-HEALING POROUS MATERIAL

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As disciplines reach maturity, a dynamic meta-structure is needed, which facilitates merging and new divisions of disciplines. Under such a meta-structure, the disciplines propel the evolution of knowledge, but adapt themselves when driving forces emerge sufficient to provoke their adaptation (Suarez-Orozco, Satin-Bajaj, 2010). This means that on the science, technology, engineering and math (STEM) education must give transdisciplinary view (Flogie, Aberšek, 2015). Science-education research studies and STEM teachers' classroom experiences have shown that analogies and transdisciplinar point of view, when *used properly*, can help make science concepts meaningful to students.

Throughout the history, analogies have played an important role in scientific discoveries, not as proof, but as inspiration. Analogies have also played an important role in explaining those discoveries (Kaiser, 1989). Science teachers, like scientists, frequently use analogies to explain concepts to students (James, Scharmann, 2007). The analogies serve as initial models, or simple representations, of science concepts.

Effective analogy use fosters understanding and avoids misconceptions (Duit, Roth, Komorek, Wilbers, 2001). In order to use analogies effectively, it is important to understand exactly what an analogy is, how it can help learning, and what kind of analogy is best. So we need explanation, logical explanation summarized in the following schema (Hempel, 1970):

Logical deduction	$C_1, C_2, \ldots\ldots C_k$	Statements of ancetended conditions	Explanans (bone remodelling)
	$L_1, L_2, \ldots\ldots L_k$	General law	
	$\rightarrow E$	Description of the empirical phenomenon to be explained	Explanandum (self-healing artificial materials)

An analogy is a comparison of the similarities of two concepts (Hempel, 1970). The familiar concept is called the *analog* (explanans) and the unfamiliar one the *target (explanandum)*. Both the analog and the target have *features* (also called *attributes*). If the analog and the target share similar features, an analogy can be drawn between them.

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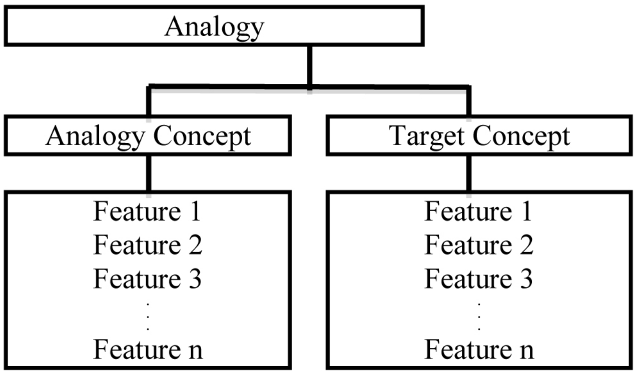

Figure 1: A conceptual representation of an analogy, with its constituent parts.

A systematic comparison, verbally or visually, between the features of the analog and target is called a *mapping*. A conceptual representation of an analogy, with its constituent parts, appears in Figure 1.

From Nature to Engineering Design

Bones appear to be a solid and strength substance in our bodies that make up our skeleton. They don't seem to change much after our teenage years. Actually, bone is a dynamic tissue that is constantly being destroyed and reformed in a process known as bone remodelling (self-healing). There are two main cells involved in this process, *osteoblasts*, the cells that create bone, and *osteoclasts*, the cells that remove bone. With analogy and appropriate mathematical model it is also possible to explain artificial self-healing material, as it is shown in figure 2

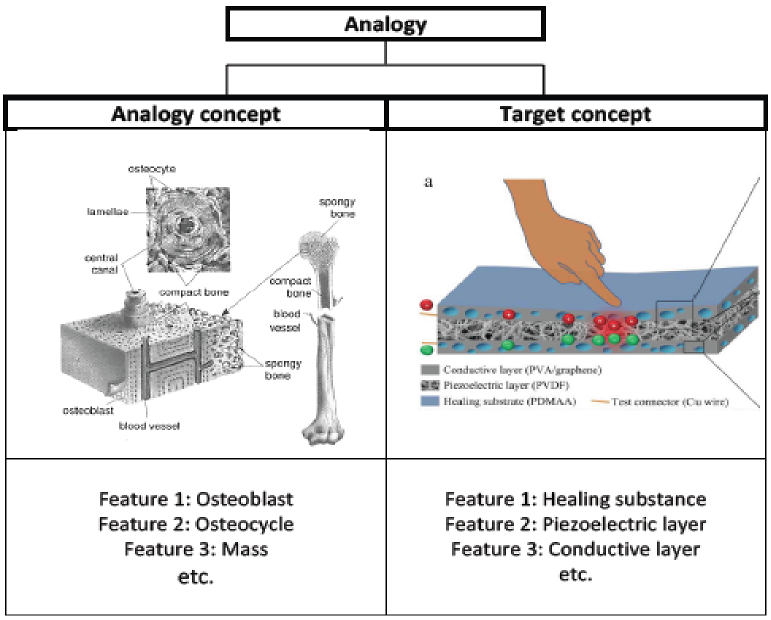

Figure 2: A conceptual representation of an analogy, from natural to artificial self-healing material.

The normal bone model (Komarova, Smith, Dixon, Wahl, 2003) is a discrete site model for single event remodelling and internally regulated cycles of remodelling. When a mathematical model is built, it can be adapted and used for a variety of materials, including artificial ones. In such a way, through mathematics and analogy method we can connect base science (biology, physics, chemistry) with their application (technology and engineering) and understanding of the natural process can help to understand how man can recreate the natural processes and produce an artificial material. We can transform the remodelling rule according to Figures 2 and 3. Remodelling algorithm could be used for different class of materials (Ren, Vesenjak, Öchsner, 2008).

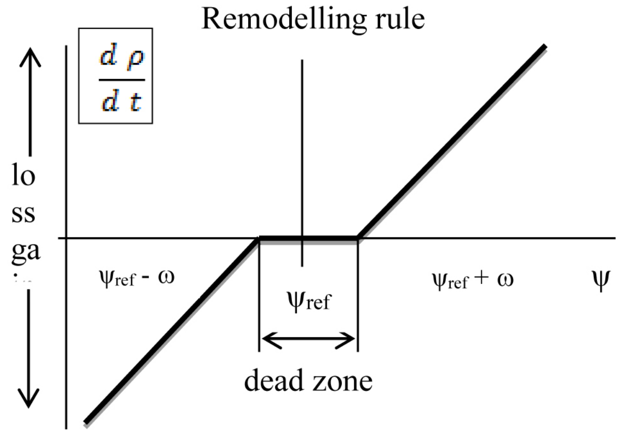

Figure 3: Remodelling rule.

As Duit et al. (2001) noted, "*Analogical reasoning is a key feature of learning processes within a constructivist perspective: Every learning process includes a search for similarities between what is already known and the new, the familiar and the unfamiliar*" (p. 285). STEAM teachers should support students' learning by using analogies effectively. The models presented here in figures 2 and 3, which simulate the mechanical behaviour of bone at the organ level, could also play a significant opportunity to understand all other similar phenomena, which are not so well known, as are artificial, bone similar materials

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