FORCE DYNAMIC GESTALT OF NATURAL PHENOMENA: TEACHING THE CONCEPT OF ENERGY

Hans U. Fuchs[1], Federico Corni[2], Enrico Giliberti[2], Cristina Mariani[2]

[1]Center for Applied Mathematics and Physics, Zurich University of Applied Sciences at Winterthur, Winterthur, Switzerland

[2]Dipartimento di Educazione e Scienze Umane, Università di Modena e Reggio Emilia, Italy

Abstract. Modern cognitive science in general and cognitive linguistics in particular teach us about basic figurative structures of the human mind which are used to conceptualize natural, psychological, and social phenomena and processes. These figures of thought are based on schematic structures that develop early in the life of a child. We have identified a structure, the Force Dynamic Gestalt, which underlies both everyday language and reasoning and the formal science of physics. If teachers learn to make use of these figurative structures, they are in a position to produce well-crafted narratives with which they can confidently teach otherwise complex and formal subjects. We demonstrate how to use the approach for developing the energy concept in primary school. The method lends itself well to a deliberate movement from the affective and qualitative to the logical and quantitative, and to the use of role games, stories, outdoor activities, laboratory work, drawings, writings etc. Linguistic and graphical tools will be described that make this approach not only simple but also natural.

Keywords: Cognitive linguistics, image schemas, metaphors, force dynamic gestalt, energy.

1. INTRODUCTION

Many studies have identified "misconceptions" in pupils' understanding of the energy concept. Some researchers (Solomon, 1983; Watts, 1983; Duit, 1984; Trumper, 1990, 1991; Logman et al., 2010) have created categories and conceptual frameworks for describing children's ideas concerning energy. Krugher et al. (1992) found that teachers often share these same naive ideas. Generally, authors find that learning the concept of energy has little lasting effect on students (Finegold and Trumper, 1989; Trumper, 1990a; Kruger et al., 1992). A possible strategy for improvement is to start with what children know and then modify their knowledge. Ogborn (Ogborn, 1990; Boohan et al, 2001) notes that "we, like other animals, are built to pay attention to differences." He suggests that in developing the energy concept, we should make use of children's spontaneous thought by paying attention to perceived differences that drive processes.

Here, we present an extended and unified analysis of deep-rooted thought processes and show how they may be employed in teaching the energy concept. We shall demonstrate how humans describe *generalized forces* such as pain, justice, imagination, light, heat, electricity, and many others. We commonly use image schemas that are projected metaphorically onto the gestalt of a phenomenon. The three most important schemas are those related to *intensity*, *quantity*, and *force* or *power*. Note that we do not use the term *force* in the sense of force in Newton's laws. Nor do we use the word *power* in terms of the physical concept power (as in the rate at which energy is released in a process). However, we will *associate* the schema of force or power with energy when creating theories of physical processes.

2. ENERGY AND THE FORCE DYNAMIC GESTALT

When children and adults speak spontaneously about physical processes, they do so in a form that reveals what we call the *Force Dynamic Gestalt* (FDG; Fuchs, 2007, 2010a). Cognitive linguistics (Lakoff and Johnson, 1999; Johnson, 1987; Talmy, 2000) shows that we base understanding upon certain schematic figures of thought that show up in language. Three of the most important are used to conceptualize natural, emotional, and social phenomena ranging from heat and light to pain and justice. The three schemas that form the basis of the FDG are quantity (size), quality (intensity and its differences), and force or power (see Fig. 1). (There are additional schemas that structure our understanding of forces such as balance, resistance, container, etc., which have been identified by Talmy (2000) in his theory of force dynamic structures of our language of causation.) These schemas are projected metaphorically onto a phenomenon in question (Fig. 2). We say, for example, (1) that there is heat in a room and that it can flow (metaphor: heat is a fluid substance), (2) that heat becomes more intense or that the temperature rises (metaphor: heat is a thermal landscape in which bodies move up and down or along a scale of hotness), and (3) that heat can be the cause of other processes (metaphor: heat is a powerful agent).

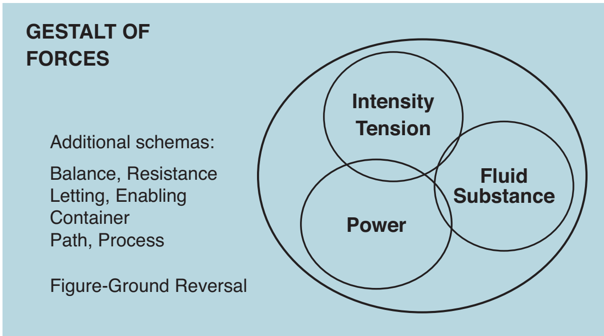

Figure 1. Schemas making up our conceptualization of a gestalt of forces (the Force Dynamic Gestalt, FDG).

Different phenomena (forces such as heat or electricity or others) are structured metaphorically using the same set of schemas (Fig. 2). This makes phenomena that do not have anything in common objectively similar to the human mind. As a result we see them as analogous and we can apply analogical reasoning. Note that metaphors are uni-directional projections whereas analogies are bi-directional.

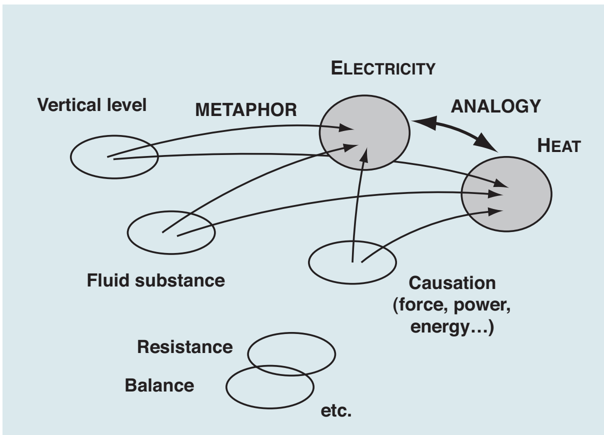

Figure 2. Metaphoric projection of schemas onto the target domain of a phenomenon. If the same schemas are used to metaphorically structure different targets, these domains become similar to the human mind which allows for analogical reasoning to be used.

We consider the third of these schematic aspects—*force* or *power*—the source of our notions of *energy*. Note that we do not have to use the word energy when speaking about it. This is certainly true for children, but also for adults. If we want to understand the energy principle as growing from the aspect of the power of a natural phenomenon, we need to learn about the schemas of fluid substance, (vertical) scale and its differences, and direct manipulation. We need to understand how the three are distinct and related (for example, the power of heat is proportional to a quantity of heat falling through a difference of temperatures, and proportional to this difference; this is Sadi Carnot's explanation of the power of heat in heat engines, see Fig. 3 and Fuchs, 2010b). This goal can be best achieved in early education by making use of well crafted stories that employ the power of schematic structures identified in narrative thought (Fuchs, 2010a).

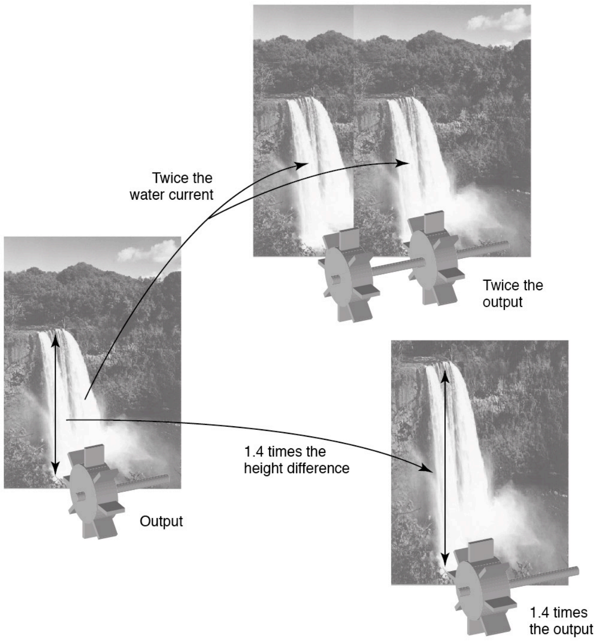

Figure 3. Sadi Carnot's image of the power of heat engines in analogy to the power of a waterfall.

It has been demonstrated that the conceptualizations used in macroscopic physics follow the structure of the FDG (Fuchs, 2007, 2010b). Processes are described as the result of the storage, flow, and production of fluid-like quantities (amount of substance, momentum, charge, entropy…). Transports, production, and storage are related to differences of intensive quantities (chemical potential, velocity, electric potential, temperature…), and the power of a process is determined as the product of current and potential difference. Therefore, we can construct the scientific concept of energy starting in early childhood if we nurture these everyday figurative conceptualizations that are, at the same time, the schematic structures of a formal science. By stressing the utility of every-day thought we do not mean to oversimplify a difficult subject, or to adopt a naïve view of understanding of nature. Rather, we want to let human thought evolve naturally using its own strength. Clearly, a teacher-training program based on the concept of the FDG can further this goal.

3. INTRODUCING TEACHERS TO THE ENERGY CONCEPT

Teachers have to be comfortable with their understanding of a principle before they can teach it confidently. We believe that if they know the foundations of a child's language concerning natural processes—which are the foundations of their own language as well—they will be in a position to be self-confident and creative in their teaching.

Here is an example of the use of everyday language that reflects the FDG and shows how the energy concept can be developed. Consider a watermill using the fall of water to grind flour. The story starts with a tension in the form of a height difference through which water can fall. This drives the millwheel and the millstone. The power of the water is quantified in terms of amount of water and height difference. The millstone (runner stone) turns relative to the stationary bedstone and the wheat between. Because of friction, the runner stone communicates its spin to the stationary stone and from there to the earth. At the same time, wheat is ground and some heat produced. Note that there is a tension, a speed difference, between the two stones, and we can introduce the notion of power of the rotational process. In summary, the falling water causes the millstone to turn which causes the grain to become flour and heat to be produced. Viewed from a different angle, two differences or tensions are produced in the course of the processes: grain versus flour and the temperature of the stones relative to that of the environment.

So far, the word 'energy' has not been used. We need this concept if we try to interpret the processes quantitatively through relations between amounts and differences. We can say that the falling water releases energy at a rate determined by the power of the process which depends upon the flow of water and the height of its fall. As the spin drops from the fast spinning runner stone to the stationary bedstone, it releases energy at the rate which is the power of the rotational process, and the energy released is used to produce flour and heat. Additionally, we see the energy released by the falling water as being transported to the waterfall, and the energy communicated from the water to the millwheel as being passed on to the millstones and finally to the flour and the heat that are produced.

The example of the description provided here can be transformed graphically using so-called process diagrams (Fuchs, 2010b, Chapter 2). To see this let us discuss a second example, that of heat driving an electric water pump (Fig. 4). If we have two bodies of water or any other material available—one hot, the other cold—we can operate a Peltier device in thermoelectric generator mode between the bot and the cold reservoirs. The Peltier device, in turn, drives the water pump.

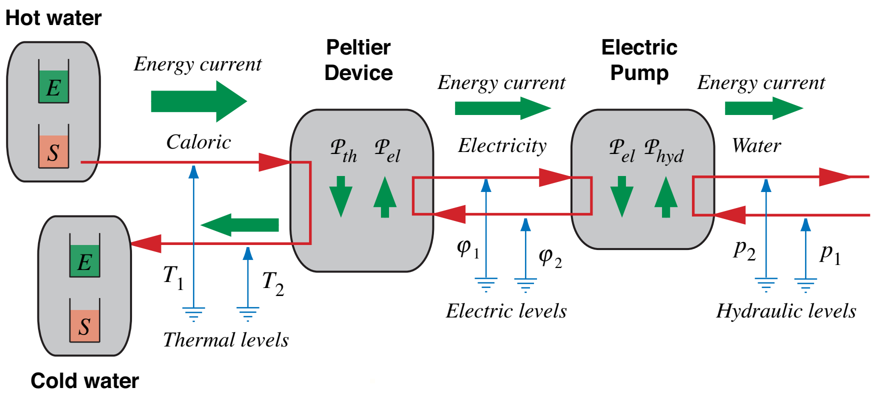

Figure 4. Process diagram representation of the chain of devices and processes leading from two bodies of water at different temperatures through a Peltier generator to an electric water pump. Fluidlike quantities representing the quantitative aspect of the FDG either fall or are pumped uphill and flow from device to device. Energy provides the coupling between processes in a device and the chaining of devices. Energy being released or used or flowing is represented by the green fat arrows. $\mathcal{P}$ denotes the power of a process.

The description goes as follows. Since the hot body of water gets colder in the process, and the colder one gets warmer, we interpret this as meaning that heat (caloric in Sadi Carnot's sense) flows from the warmer to the colder body (see the left of the diagram in Fig. 4). It flows downhill from a warm place to a cold place. In other words, we interpret the temperature as the thermal level or potential. Heat falling from a higher to a lower level releases energy at a certain rate which is used by the Peltier device to pump electricity (electric charge) uphill (from lower to higher electric potential; see the central part in Fig. 4). The energy used to pump the electricity is passed on by electricity to the electric pump where it is released; note that the electricity flows downhill—from the higher to the lower electric level—in the pump. The energy released is then used by the pump to pump water which means that the pressure of the liquid is raised from a low to a high value (right side of Fig. 4). Finally, the energy used for pumping the water is transferred with the water.

We can use the idea of *differences* or *tensions* that has played such an important role in the previous examples as a fundamental descriptive tool. For example, as the gravitational tension of the water decays, a new rotational tension is set up which itself decays to set up new thermal and chemical tensions (heat and flour are produced). The world turns on this principle: tensions beget tensions that beget tensions…

What we have seen here can be transformed into a general approach to studying phenomena and formalizing our ideas of natural processes. The steps are the following: i) description of a process as a whole using common language; ii) refinement of the language used, stressing quantities that play a role; iii) description of the process in terms of fluid-like quantities, potential differences and associated elementary concepts (current, resistance, capacitance, etc.); iv) interpretation in terms of cause-and-effect (without using the word 'energy'); v) introduction of energy quantities and energy balances. This method is appropriate for introducing pre-service and in-service teachers to narrative forms of descriptions of nature (supported by role games, stories, outdoors activities, laboratory work, drawings, writings etc.) that are eventually transformed into formal accounts. Most importantly, it is well suited to increasing levels of formalization and sophistication (from a qualitative approach using common language, up to quantitative procedures using graphs, maps, or mathematical relations). An entire graphical language, called process diagrams, has been developed that is intermediate between verbal descriptions and mathematical formulations (see Fig. 4; Corni at al., 2009; Fuchs, 2010b; Herrmann, 1998).

4. SUMMARY

If we follow modern cognitive science in general and cognitive linguistics in particular, we are led to identify basic figurative structures of the human mind which are used to conceptualize natural, psychological, and social phenomena and processes. We have introduced the Force Dynamic Gestalt as the cognitive structure that projects the schemas of quality/intensity, substance/quantity, and force/power onto phenomena, leading to metaphors. Processes are viewed as resulting from the flow of fluid-like quantities through differences of intensities (potential differences). They are forced by other phenomena, and they themselves force other phenomena in a chain of causes and effect. Energy is introduced as the measure of force/power of a process; in other words, it quantifies the relationship between cause and effect. Conceptualizing phenomena in this manner allows for a didactic approach that naturally leads from affective forms of narrative accounts to ever more formal descriptions. Linguistic and graphical tools have been developed that make this approach not only simple but also natural. It helps build the self-confidence of in-service and pre-service teachers since natural language serves as the steppingstone into the world of science.

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