Designing and Using Stories of Forces of Nature for Primary Understanding in Science

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The term *primary understanding* is used here in a dual sense. It means early education in elementary school, or even kindergarten, when children create their primary understanding of the world around them using the primary cognitive tools of the *mythic mind*. It also refers to the understanding of concepts of science which may rightly be called primary: the concepts associated with *forces of nature* such as water, air, fire, cold, light, motion, electricity, food or mineral resources, to name a few obvious and important ones.

Stories appear to be the perfect vehicle to introduce these forces of nature—and the ways in which we understand them—to small children. In this essay, I would like to discuss some of the aspects to consider when we construct and use such stories. These aspects include (1) the formation of polarities from the perception of differences such as light and dark, strong and weak, or hot and cold, and their importance for mythic understanding; (2) the use of different polarities for the same phenomenon to combine human concerns and a force of nature in a story; (3) the use of our senses of fantasy and causality; (4) the gradual shift toward conscious knowledge in the child of aspects of the gestalt of these forces of nature, i.e., the conscious differentiation of the aspects of intensity, quantity or substance, and force or power; (5) the growing use and awareness of secondary image schemas associated with the gestalt of forces such as balance, resistance, enabling, and container; (6) the development of the character schema of stories and its quantitative and formal aspects—such as counting, measuring, calculating and answering if-then questions—in the course of education; (7) the pedagogy of applying stories in the classroom, i.e., telling stories, asking questions, and letting children tell and write their own stories; (8) finally, the question of how to tie all of this in with language and mathematics education and the arts. Learning about how to build and use such stories will allow teachers to become self-confident, creative, and competent storytellers.

In the first section of this essay, I will introduce a deliberately crafted story to give the reader a concrete background for the following discussions. In Section 2, origins and uses of polarities will be described. I will then show how to create the characters or agents—including their role in fantasy and our sense of causality—behind forces (Section 3) and conceptualize their power (Section 4). Section 5 is devoted to a brief outline of how we can include subsidiary image schemas used to talk and write about forces of nature. In Section 6, the development of the character schema in the course of a series of stories is outlined. A short summary is presented in Section 7.

1. Summer Story—A Tale of Heat

Here is a short story for children in the first years of primary school that playfully introduces some of the aspects of how narrative is used in early science instruction. It revolves around children living through a particularly hot summer. They observe and learn about what powerful heat means for them and the animals and plants of their environment. The story will be analyzed further below in the following sections.

Anna and Luca were twins. They had just finished kindergarten and their parents told them that after summer they would start in real school. They were excited about this but even more so about the long weeks of summer waiting for them when they could play outside, stay up late, and just be lazy.

Summer had started gently right at the beginning of their vacation. The air felt perfectly warm and the kids did not have to sweat even when they ran around wildly. Anna and Luca remembered that a few days before they still had to wear pullovers. It just was too cold. Since then, the Sun had been shining brightly. Luca and Anna loved to feel the sunshine on their skin. All around them, the streets and the rocks, the grass of the fields and the water of the nearby pond had been swallowing up the light of the Sun making them slowly get warmer.

The twins often met with their neighborhood friends down at the pond. On their first day down there that summer, everybody but Luca took off their shoes and socks and felt the grass and the rocks beneath their bare feet. Luca did not want to admit it, but he was much more cautious than his sister and his friends. It was afternoon and the stones were pretty hot already. It did not hurt but they moved swiftly over the stones looking for patches of grass—staying on a rock for too long made their feet get quite hot. Luca wanted to show off how smart he was telling his friends that the soles of his shoes did not let the heat of the stones get through, so he was safe and could walk without trouble wherever he wanted. His friends laughed, called him a coward, and ran to the water.

When they got to the edge of the pond they carefully put their feet in the water and they were surprised that it was still rather cold. They had not believed their parents when they had told them in the morning that they would have to wait quite a few more days before the water would be warm enough for swimming. They stayed out and played in the grass and under the trees. In the evening, Anna and Luca went home where their parents had set up dinner on the balcony. The windows of their home were left wide open to let the heat that had settled in the street below into their apartment.

What nobody knew, not the grownups and not the kids, was how hot this particular summer was going to get, and how hard the heat of summer was going to make everybody's life. As the days went by, it got hotter and hotter. Even the nights were not really cool any longer. A day would go from warm in the morning to hot at noon to very hot in the afternoon. For Anna and Luca, the first signs of what was to come was that their mother talked about temperatures that had never been so high so early in the year and that she had heard on the news that this was predicted to last all through summer. Their parents pulled the shutters and closed windows and doors as soon as *the Sun showed its face over their town. The kids knew the Sun shining into the apartment would make things hot, but they had not thought about what their father explained: they had to keep the air from the street out. The air was so hot during the day that it brought with it huge amounts of heat that would be left in their home did they not close the windows and doors.*

Then their mother started watering the plants on the balcony much more than ever before. Luca and Anna knew why: the heat was drying up the soil very quickly. They had seen what happened the day before. After a thundershower, the Sun came back out from behind the clouds very quickly and its rays turned the water on the dark streets into steam. When they watched carefully, they could see faint clouds rising from the asphalt.

Summer showed its strength when the children of the neighborhood went back to the pond. The water had finally become so warm that even Luca enjoyed jumping in and swimming—he who would get cold so quickly. While his friends did not find the water refreshing any more, he could not get enough of it. When he finally came out he joined his friends who were playing soccer in the nearby field. He ran after the ball as hard and as long as he could. When his sister called him waving the hat in her hand that his mother had told him to wear, he ignored her. He could show everybody how tough he was. But that was a mistake. He started feeling dizzy, then his vision went black. When he woke up again, he saw grownups around him that had been called by his sister and his friends. One of them was a doctor whom he heard saying to his mother: "It is so warm out, his body just could not get rid of all the heat inside it any more. Keep him cool with some ice and let him drink lots of water. And he has to wear a hat. He will be fine."

Other creatures were not as lucky as Luca was that day. The heat of summer was so powerful that the land dried out faster than the few rain showers could deliver new water. The heat was spreading into larger and larger areas around where Anna and Luca lived and it was hotter and drier than ever before. Plants in the fields died and the farmers complained to the journalists who would report about the summer of the Century on the evening news. They also showed how some people stood in what little water was left in the nearby river and tried to catch the few fish that were still alive. They wanted to take them to a bigger river that still carried enough water.

When things got too hot even for the children to enjoy themselves, when both Luca and Anna got cranky, their father told them they would go to a museum in town. They did not really want to go. His telling them that the big old building that housed the museum would be still comfortably cool did not convince them. He had to bribe them with a promise of lots of ice-cream. They took the bus that was air-conditioned—that's what grownups called it—and cool. When they got off and the bus drove away, Anna stood right where a huge gush of really hot air came out of the side of the bus and made her almost jump.

Their father bought them large ice-creams, as promised, but they could not enjoy them for very long. As they walked over to the museum, the intense heat made the ice-cream melt so fast that they lost much of it and they made a mess of themselves. Wisely, their father had brought tissues along and helped them clean up. When they finally were in the museum, it was indeed so pleasantly cool that they started getting more *energetic again. Their father had been right. The huge thick walls of the old building had kept the heat out even after so many days of terribly high temperatures. Anna thought about this. She was sure that the heat in the streets had tried to get into the building just as it did at home. She wondered if their apartment got so much warmer so much faster because the heat had an easier time sneeking through the thinner walls of their building.*

Back at home, Anna asked her mother what this heat actually was that everybody was talking about. Did it really exist? She could not see it. She knew it was hot, very hot, but what was this heat thing? Her mother then started telling her a story—which she knew Anna loved—of a little boy who had died and become a ghost. At the end, her mother told her that heat was like the ghost in the story. We could not really see the ghost, but we knew he was there creating all the mischief and fun that happened in the story. That's how heat was responsible for all the things that had happened this long, beautiful and yet terribly hot summer.

As I said before, this story has been designed to serve as an example of some of the aspects of narratives that are important in my essay. It is built around polarities having to do with the phenomenon of heat and demonstrates how to use them. It may serve to develop our sense of polarities and how to use them in language and for constructing the meaning of a phenomenon (Section 2). It introduces agents and there is a section that applies fantasy (Section 3). The Force Dynamic Gestalt (FDG; see Fuchs, this volume) appears on the scene but the conscious differentiation of its aspects by a child is not yet a major concern. Still, there are elements of formal causal reasoning involving the power of heat (Section 4). Secondary image schemas play an important yet subliminal role (Section 5).

Naturally, since this is only a single story, elements of education that have to do with development over longer periods involving several steps cannot be included. For example, a single story cannot show us how we might evolve the character schema of narratives (for an introduction to the concept of character schema, see Fuchs, this volume). We can see the role of the character schema in the Summer Story, but we cannot see it evolve (Section 6).

2. Polarities and Forces of Nature: How to Start Stories

If we want to create and use stories of forces of nature in our classrooms, where do we start? Good stories work around tensions, dilemmas, predicaments, perplexing situations, etc. The roots of tensions are found in the perception of differences, i.e., in polarities (binary opposites). Egan (1986) has suggested that we start narratives by looking for appropriate polarities that set up the dilemmas and predicaments necessary for the dynamics of a story.

In this section, I want to discuss examples of *polarities*, show how they are related to what we call *generalized forces* in life and nature, demonstrate how they lead to the aspect of *intensity*, and describe possibilities of using and developing them in the classroom. An important element of the discussion concerns how we can make use of different polarities for the same phenomenon to develop both general *human concerns* and *scientific aspects*. Then, in Section 3, we will see how the gestalt of forces of nature obtains additional complexity by the addition of the aspect of size or quantity.

Polarities and generalized forces. Consider the Summer Story narrated in the previous section. It is above all about the *force* or *power of heat* which develops from our perception of the polarity HOT <–> COLD, i.e., from the perception of the quality or *intensity* of heat. People in the story notice the differences between cold, warm, and hot, and this shapes their experience of the phenomenon of heat resulting in a perceptual gestalt, the *Force Dynamic Gestalt* of heat (Fuchs, 2007, 2010a, and this volume). The creation of this abstraction is a general phenomenon that applies equally to social, emotional, and physical experience: our mind produces the concept of a *generalized force* for the different polarities we perceive (see Table 1; remember that *force* is not used in the sense of a force in mechanics.)

The Summer Story provides ample opportunity to speak about an experience conceptualized in terms of a *scale schema* (Johnson, 1987, pp. 121-124; Croft and Cruse, 2004, Chapter 7). Children can learn how to deal graphically and linguistically with scales. This is particularly intuitive and simple in the case of HOT <–> COLD. We learn that there are various sensations of hotness lying between the poles of extremely hot and extremely cold, we can learn new words and how to put them in order along a line going from one pole to another. At some point, young children can be introduced to a concept, a term, encompassing the manifold spanned by the polarity: at this point they learn the term *temperature*. Once this is introduced, children can be exposed to some interesting aspects of this concept: it can be quantified, i.e., we can provide numbers for the sensations; and when we speak about temperature we realize that we conceptualize it with the help of the *schema of verticality*: temperatures are high or low or in between (Figure 1).

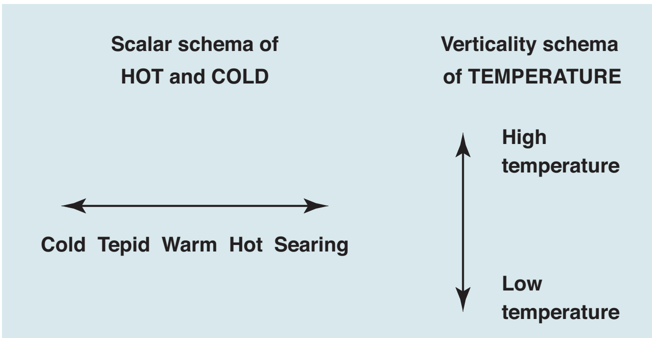

Figure 1: *Scale schema* and *verticality schema*. A polarity spans a *scale* (which may be open or closed and one or both ends). We introduce adjectives to place the intensity of a sensation on this single-dimensional manifold. When we introduce a term denoting this scale (such as temperature or speed for the thermal and mechanical polarities, respectively; see Table 1), the concept is rendered in terms of the *schema of verticality*.

We use this schema to produce metaphors, for example the metaphor of a body moving up and down in a thermal landscape, or the observer moving through materials which are differently hot and describing the motion as leading up or down, as in a landscape. Being higher in the landscape means the perceived temperature is higher. I routinely introduce the intensive quantities of a phenomenon (column 3 in Table 1) as level quantities and the process of going from a place at a certain temperature to a place at a different temperature as moving up or down. This is a common form of metaphoric conceptualization for which a beautiful example is given in Mark Johnson's analysis of music (the MUSICAL LANDSCAPE metaphor; see Johnson, 2007, Chapter 11).

As part of language education, children can pick up the theme of the scalar schema and we can suggest how to apply this form of thinking to other concepts such as COURAGE <–> COWARDICE, PAINFUL <–> PLEASURABLE, JUST <–> UNJUST, HARMONIC <–> DISSONANT, and many more, and we can show our students that we place adjectives in proper order on a line just as we put beads on a string.

Table 1: Forces of Nature and their Generating Polarities

FORCE (PHENOMENON)	**POLARITY**	**VERTICALITY SCHEMA**
Light, Darkness Sunlight	LIGHT <–> DARK	Brightness
Heat, Cold Fire, Ice	HOT <–> COLD	Temperature
Fluid, Gas Water, Air	HIGH PRESSURE <–> LOW PRESSURE	Pressure
Humidity, Draught Water, Fog, Steam	WET <–> DRY	Humidity
Gravity	HEAVY <–> LIGHT	Gravitational potential
Sound	LOUD <–> QUIET	Loudness
Movement Rest	FAST <–> SLOW	Speed
Food	HEALTHY <–> POISONOUS	Nutritional value
Substances (chemical) Soap, Medications, Herbs, Fuels	AGGRESSIVE <–> GENTLE	Chemical potential
Salt, Sugar, Medications	CONCENTRATED <–> DILUTED	Chemical potential
Electricity	ELECTRIFIED <–> DISCHARGED	Electric potential

Choosing polarities. Our sensations resulting from interaction with nature provide us with a fairly large number of possible polarities (Table 1). A particular type of sensation may be looked upon as the generator of a particular perceptual gestalt of a force. When we wish to produce stories of the type I am discussing here, we can just analyze our perceptions of natural phenomena and pick from a long list. The list shown in Table 1 serves as an example of what I mean. There are other polarities, additional forces, and different ways of bringing order into our rich experiences of the natural world around us. Just take the case of chemical phenomena, i.e., phenomena associated with the shear endless number of substances. I have called the polarity AGGRESSIVE <–> GENTLE; we could just as well speak of STRONG <–> WEAK (strongly or weakly reacting) or, if we wish to narrate phenomena having to do with the flow of substances (diffusion), of CONCENTRATED <–> DILUTED. And speaking of the forces (the left column in Table 1), we may list any interesting substance that fits our particular purpose. For teachers of young children, it is important to accept that we do not have to produce a perfectly ordered, cleansed, formal science here. We can pick and choose and produce good stories. What makes for a good story is not determined by its adherence to a sanitized and formalized scientific structure but to how the schematic, metaphoric, and narrative—the *figurative*—aspects of the story are dealt with (see Corni, this volume, for a proper list of scientific concepts). This lets us confront many interesting and worthwhile educational challenges having to do with science, language, mathematics, art, or social studies.

Human drama and agents of nature in the same story. Notice that there is a second polarity associated with the phenomenon of heat: HEAT AS HELPER <–> HEAT AS DESTROYER (Egan, 1986, p. 98). Heat as a force has great human value and impact leading to human drama. In the story told above, this aspect of heat provides a unifying thread through the narrative, a thread created by the affective power of the larger (human) meaning of the character of heat. This polarity holds the story together in a more general sense than the purely natural aspect of heat would or could—at least for children.

We can work on this polarity just as we can on the polarity HOT <–> COLD as described above. This leads to a concern different from the sciences proper, and we might argue that we do not have to deal with it in science class; but we certainly can and should in language and social studies. At any rate, in early primary school we do not have to draw clear lines of demarcation between fields of study as we do in later phases of education.

I could have used a different polarity to set up the human side of the story such as CONCERN FOR NATURE <–> DISREGARD FOR NATURE. Anna and Luca could have been portrayed as caring deeply about the fish in the nearby river, being interested in them for whatever reason. Now comes the heat of summer and threatens the wellbeing of the animals. Clearly, the polarity of heat as helper/destroyer is involved here too. Put simply, a story can easily be an entire network of interacting polarities.

In our story, there is a tension at a meta-level, the tension between what I call the *story schema* and the *character schema* (see Fuchs, this volume). Simply, it is the tension between the *human concerns* created by heat and *heat as a force of nature*. This tension can be exploited educationally if we are aware of it and learn to develop both schemas during the growing years of our students. How to develop the relative importance of these two aspects will be the subject of Section 6.

Polarities in a chain of cause and effect. Here is an aspect of the network of polarities in a story that has far reaching consequences for education in general and for science education in particular. There are other less central polarities present in the story, namely DRY <–> WET/HUMID (in the case of soil or air), ALIVE <–> DEAD (plants and fish), or LIGHT <–> DARK (sunlight). Take the first of these. When we read that "…the heat of summer was so powerful that the land dried out faster than the few rain showers could deliver new water...," we notice how a new polarity is created by, in fact is causally linked to, the primary polarity HOT <–> COLD. We can say equally well that the force of heat brings about a new force, that of drought. The theme of polarities and their associated forces lends itself to an early engagement with the *notion of causality*. How much a teacher wants to dwell on this and at what age of the students is a question best answered by experience. The issue of how to conceptualize—and even quantify—the notion of causality will come up sooner or later anyway.

There is another way of dealing with causal reasoning when polarities are introduced in class. Through much of human history, it seems, people have reasoned as follows: differences drive the dynamics of this world. In other words, differences of qualities (intensities) have been assumed to be the reason for why and how things happen. This was so in Egyptian and Babylonian cosmologies (see Fuchs, this volume) and we find it in modern thought—maybe not put so clearly and beautifully. If we are attentive we see that this reasoning pervades all of modern physics. In our simple story, the difference between the searing temperatures of the hot air and the temperatures of the soil, water, and homes is the driving force for much of what is happening. Equally, the missing temperature difference between the air and Luca's body is responsible for the fact that he cannot cool off properly—in other words, lose heat at a proper rate—and suffers a heat stroke.

3. Introducing the Quantitative Aspect of Characters or Agents

A phenomenon has the aspect of quality or intensity (or rather differences of qualities or intensities) introduced by direct perception that leads us to the concept of polarity. It also carries with it the aspect of *size* or *quantity*. A force of nature, a character or agent, can be larger or smaller, or there can be more or less of it in a given case. The air in the streets of Luca's and Anna's town can carry more or less heat with it.

We easily speak of heat and even learn to speak of quantities of heat. We teach our children these words so they learn to use them early on. The question remains of where the notion of a quantity of heat comes from, how it is best developed in the course of education, and how children learn to make use of it in a way that lends itself to later formalization in the sciences. It is certainly true that the perception of *objects* or *substances* is quite fundamental. [Still, the concept of object may be secondary to that of differences or tensions: the human mind constructs objects from the perception of differences, see Arnheim, 1969.] That does not tell us, however, how we construct the notion of objects or substances we cannot see.

Fantasy. In the story I included a short part where Anna's mother uses a fantasy story about a ghost to show how we create characters as the result of the perception of a polarity. Egan (1986, 1988, and this volume) argues that the polarity ALIVE <–> DEAD suggests to the human mind creatures that populate the spectrum between what we grownups take as the two elements of the dichotomy of alive and dead. Between beings that are either alive or dead, children introduce ghosts quite effortlessly. In science we usually do not think of it in this way but heat as a character or agent is not that far removed from the ghosts of children's fantasy stories, nor is quantity of motion or quantity of electricity. These are the fantastic characters we deal with in our formal scientific accounts of phenomena such as heat, motion, or electricity. Therefore, it may not be so far-fetched after all to use fantasy to suggest to children to do the same for the forces of nature we introduce them to. There are, by the way, agents that are visible and material such as water, air, and the myriad substances populating our world. Introducing a measure of quantity for them is not that difficult.

In our stories, we need the concept of quantity or amount when dealing with forces of nature (see Table 2 for a list of such concepts and terms). We do not just need to know how hot the air is, we also need to know how much hot air there is. If we imagine heat to be in the air, the more air there is the more heat there is as well. What holds for thermal phenomena also holds for all the other examples of the Force Dynamic Gestalt.

Dealing with amounts. The language used in the Summer Story tells a great deal about how we think in terms of quantities. If we become aware of the metaphoric nature of our narrative, we can infer the types of conceptualizations that go along with the aspect of quantity of heat (see Table 3). Above all, there is a *quantity of heat*; our words testify to the fact that we think in these terms. This quantity is contained in spaces or rather in the material substances contained in these spaces: there is more or less heat in the air in the streets, in the apartment, in the rocks, or in the water of the lake. Heat can go into or out of these materials, it can flow, it can be transported. And, even though it is not stated in so many words, the rays of the Sun produce heat in the bodies where the sunlight is absorbed. All in all, we are dealing here with the conceptual metaphor HEAT IS A FLUID SUBSTANCE.

Table 2: The Aspect of Quantity of Physical Forces

FORCE (PHENOMENON)	QUANTITY
Light, Darkness (Sunlight)	Amount of light
Heat, Cold (Fire, Ice)	Quantity of heat
Fluid phenomena (Water, Air)	Amount of fluid, Volume of fluid
Humidity, Draught	Amount of water
Gravity	Gravitational mass
Movement	Quantity of motion (momentum) Quantity of spin (angular momentum)
Substances (chemical)	Amount of substance
Electricity	Quantity of electricity (charge)

There are ample consequences of this metaphor and learning to deal with them is a worthwhile part of education. Let me list just some of the aspects that come to mind. We make use of the *container schema* and its abstract structure which gives us the concept of *in and out* and how to use them logically; specifically, heat is in the air and air is in a room, so heat is in the room (this is an instance of formal logic: if A is contained in B, and B is contained in C, so A is contained in C). Heat as a fluid in a container suggests that more heat will make the materials hotter. This is an instance of the metaphor MORE IS UP: more heat leads to higher temperature. The typical result of the relationship between *quantity* and *intensity* of heat of a substance is the confusion of the two: in everyday life we often do not treat these aspects as different from each other. For science, however, it is very important that we learn to differentiate the two. If we have our students deal with this challenge successfully, we will have done a great job educating them for their future science courses.

Table 3: Metaphors for Heat in the Summer Story

METAPHOR	LINGUISTIC METAPHORIC EXPRESSIONS
HEAT IS A (FLUID) SUBSTANCE	*…telling his friends that the soles of his shoes did not let the heat of the stones get through.* *…to let the heat that had settled in the street below into their apartment.* *The air from the street was so hot during the day that it brought with it huge amounts of heat.* *The heat was spreading into larger and larger areas…* *She was sure that the heat in the streets had tried to get into the building…*

We treat heat as being able to flow so we are led to introduce the concept of *current* having aspects of *strength, origin, and direction*. Finally, we know that if something flows into a container, it adds to what is already in there. This tells us that we have to learn to *account* for quantities of heat, i.e., to master the art of keeping track of the fluid substance we call heat.

Applying bookkeeping to fluid substances that are contained somewhere and can be produced and can flow, is a fairly complicated mathematical affair if it is driven to extremes, but it has simple and important aspects suitable to early education. In its simple form, it means counting objects and keeping track of them as they move around from container to container. This is certainly a useful challenge for small children and it can be dealt with in playful manner in the classroom. Similarly to level quantities (the quantities for which we apply the schema of verticality) where we can introduce children to ordering and measuring differences, counting quantities brings together mathematics and science education early in the curriculum. A story based approach to the quantitative aspect of phenomena has been developed by Corni et al. (2010).

Systems thinking and system dynamics modeling. Incidentally, this yields an occasion for the introduction of *system dynamics modeling*, a methodology where tools have been developed to deal with the mathematics behind laws of balance in a graphical manner. Jay Forrester and co-workers are actively working to create pedagogy and materials to introduce even very small children to the tools of system dynamics modeling (Forrester, 2009; Roadmaps, 1990). Systems thinking and dynamical systems modeling go far beyond the technique of applying *laws of balance* to quantities (the fluid substances of the corresponding metaphor). However, it is a great tool for us that helps us think about how to work with the amount of metaphorical fluid substances and how to introduce counting them in the classroom (Fuchs, 2002).

4. The Power of Forces of Nature

The Summer Story is full of incidences of the power of heat—expressly or subliminally (see Table 4 for examples). In this section, I will discuss the aspect of force or power of phenomena and then show how it can be dealt with in early education.

Heat as an agent and a patient. If we say "The heat of summer was so powerful..." there is no mistaking this aspect of the Force Dynamic Gestalt of heat. Take, however, the expression "It was afternoon and the stones were pretty hot already," which implies that the heat of the afternoon is responsible for making the rocks hot. There is no direct mention of heat let alone its force or power but we know what is meant: *heat is a causal agent*. This aspect shines through even more meaningfully in the example "…[the Sun's rays] turned the water in the dark streets into steam." Here, heat (the heat produced by the Sun's rays) does not just make something hot, it causes a different type of phenomenon to occur: it forces water to become steam (a chemical process so to speak). The same point can be inferred from "The heat of summer was so powerful that the land dried out faster… ."

One of the entries in Table 4 is of a rather interesting sort: "…Anna stood right where a huge gush of really hot air came out of the side of the bus." Obviously, she experiences the result of air-conditioning: the air-conditioning equipment installed in the bus *forces heat* out of the bus. From other observations we gather that heat flows from hotter to colder places. Since it is colder in the bus than outside, the flow of heat seems to go against its own nature; therefore it has to be forced. If we think about it, we see what this means: there must be another process (force, power) that is responsible for making heat flow against its nature. Heat has been forced to do this. In cognitive linguistics one speaks of an example where heat is not the agent but the patient (Talmy, 2000; Lakoff and Johnson, 1980).

Table 4: Metaphors for Heat in the Summer Story

METAPHOR	LINGUISTIC METAPHORIC EXPRESSIONS
HEAT IS A FORCE-FUL AGENT… …OR A PATIENT THAT MUST (OR CAN) BE FORCED	*…they still had to wear pullovers. It just was too cold.* *…and how hard the heat of summer was going to make everybody's life.* *…the Sun came back out from behind the clouds very quickly and its rays turned the water on the dark streets into steam.* *The heat of summer was so powerful that the land dried out faster…* *…Anna stood right where a huge gush of really hot air came out of the side of the bus…*

Children hearing or reading stories of the Summer Story type will probably have a good but still unconscious understanding of the conceptual structures contained in them. They have to be supported in a gradual shift toward conscious knowledge of the aspects of the gestalt of the forces of nature. In other words, they should be instructed to consciously differentiate between the aspects of intensity, quantity or substance, and force or power.

A qualitative approach to the causal role of forces of nature. The aspect of force or power can be transformed into the concept of energy and rendered quantitative and formal (Fuchs et al., 2011). In my view, a more or less direct approach to energy in physical processes is sensible only for older children, maybe around the age of 10-12 or even later (there is a physics course starting at age 12 or 13 that uses imagery similar to the Force Dynamic Gestalt; see Herrmann, 1990). However, I believe that the years before this can and should be used for a careful qualitative approach to the concepts of causality and the power of a force of nature. Solving the task alluded to above—learning to differentiate between intensity, quantity, and power—is prerequisite to a good understanding of the role of energy in physical processes. It is no small feat to achieve this and it will take time if done properly.

This leads us to the challenge for early education: we must develop and use narratives that strengthen the elements of mythic understanding; we find the elements necessary to talk about the aspects of the Force Dynamic Gestalt there and in modern language. There are linguistic tools that can be constructed for younger students and graphical ones for somewhat older ones to deal with the aspects of forces of nature. The more the children know about how to manipulate these tools and the better they can tie descriptions of nature to basic figurative concepts developed during the mythic phase, the better they will be equipped later to make sense of the energy principle.

The difference between tension, quantity, and power. Having introduced the forces of nature as characters or agents should make it easy to suggest that they are powerful, that they influence other things in nature, that they cause other things to happen. Still, the job of learning to recognize power as an aspect has its pitfalls. Linguistically, it is not easy to distinguish between a tension set up by a difference of qualities (or intensities) and the force or power of a phenomenon. As mentioned before, it makes sense to call tensions *driving forces* of processes; this introduces the notion of causation. Therefore, children have to learn to distinguish between these driving forces and the force/power of a phenomenon. We may want to use the word *power* rather than force when speaking about the measure that will later be turned into the energy concept. Equally confusing is the fact that the quantitative aspect of a phenomenon is strongly tied in with the feeling for causation—the character or agent of a force of nature as the representative of causation. In simple words, the three aspects of the FDG are so closely related that telling them apart is no easy job.

Take electricity as an example. This can be a tough one since we do not see what we are dealing with—actually, in this respect it is no different from most forces of nature—we feel if we get an electric shock and otherwise we see only certain things happening as consequences of electricity. This would be all we have to go by if it were not for this fundamental way of thinking and speaking that comes along with the FDG. If we are attentive, we notice that linguistically, we have three distinct concepts for dealing with electricity. We might say that electricity can be intense, or that there is more or less electricity, and that electricity can be powerful. Note how closely related these three forms of speaking can be. If we talk about the intensity of electricity we may say equally well how strong electricity is; this relates it directly to the force aspect. Moreover, since we only see the effect of electric processes, not electricity itself, the power of these processes as a measure of how much is effected may be used as a replacement for the quantity of electricity. Basically we do this when we have to pay the electricity bill and say that we have used a lot more electricity this month than last month. Note also how subtly unclear the language of experts is in respect to the quantity of electricity. If they speak about electric currents, this is done in two forms that cannot be distinguished easily if we are not trained linguistically. They use expressions such as (1) here flows a current (of electricity) or (2) current flows. In (1), *current* is a *count noun*, in (2) it is a *mass noun*. In other words, the two senses of current are totally different. In the first case, we are talking about something—a fluid substance, i.e., electricity—flowing. In the second case current is used in the sense of a substance (that flows); we may actually read expressions such as "current flow" written by experts in the field.

Developing a sense for electric phenomena will require careful work with children over the course of years. This work must involve the development of ways of saying things—talking and writing—and drawing pictures and diagrams to express what we mean and understand. These activities should go hand in hand with the investigation of actual electric systems (with batteries, lamps, little motors, etc.) of increasing sophistication. Teachers doing this will be reminded every step of the way how difficult it is to distinguish between the three main aspects of the FDG, but there is no way around this if we want to do a good job of preparing our students for understanding forces of nature. Again, let me stress my belief that good stories plus accompanying activities are the best tool we have to deal with this challenge.

The relation between tension, quantity, and power. There is a complementary way of dealing with the question of how to differentiate between intensity, quantity, and power, if we ever want to understand the role of power. We have to make clear *how the three are related* which will lead us to the question of how to introduce children to quantitative (or at least semi-quantitative) reasoning. A sense must emerge from the stories that the power of a process grows with growing intensity (tension) and with growing quantity. Power depends upon *both* tension and quantity; we need tension and quantity to understand power, so power is a *third* concept, different from the other two.

Let us return to the Summer Story to see how a sense of the relationship between power and the other two aspects may emerge. Consider the melting of the ice-cream (or the evaporation of water in the streets) and the air-conditioning of the bus. In the first phenomenon, we need more heat to melt more ice-cream, and if the temperature difference between ice-cream and surrounding air is is higher, the process runs faster (this is actually an indirect effect: higher tension lets heat flow into the ice-cream faster, so heat arrives faster and can do its job more quickly).

The second case is more clear-cut if reversed. Here, heat is the patient. If we have an electrically driven bus, it is the electric engines that work to make the air cooler. We notice that the engines have to work harder—their power has to be higher—if it is very hot outside compared to inside the bus. And the power has to be higher if a larger bus is to be cooled. The power therefore has to be higher, the higher the temperature difference from inside to outside and the more air has to be cooled in a given time span. The process is analogous to pumping water; note how we have arrived at an example of analogical reasoning. Analogical thought is present to a high degree already in young children (see, for example, Atkins, 2000) and it is very important in science in general and in physical science in particular (see Fuchs, 2007, 2010b). As children learn about more and more examples of forces of nature, the question of how our mind compares different phenomena is becoming more of an issue. However, I will not go into this theme more deeply in this essay (see Fuchs, this volume, for a short discussion of the structure of analogies between forces of nature).

Working out the differences and the relationship between tension, quantity, and power cannot be dealt with satisfactorily in a single story. This will take time and many different narratives. One of the best stories for our purpose is the one told by Sadi Carnot in his famous book *La puissance motrice du feu* (Carnot, 1824). For more examples from the viewpoint of science see Corni (this volume) and Mariani (this volume).

5. Working on Force Dynamic Schemas

The Summer Story is full of examples of additional schemas that are used to structure our understanding of forces of nature. Intensity, quantity, and power are core concepts but without other figures of thought we would not get far in our accounts of natural phenomena. The structures alluded to are schemas such as letting, enabling, or blocking, identified by Talmy (2000, in his theory of force dynamics as a schematic system) and a few additional image schemas such as container, balance, etc. (see Figure 2). There are a few recurring figures of speech that are important for describing physical and other processes. Whereas the basic three of the schemas are directly linked to what physicists call generic relations (laws of balance, loop rule, energy principle; see Fuchs, 2010b), the additional schemas are needed to express so called constitutive laws (capacitive, resistive and other relations). Let us take a look at these forms of reasoning.

The language of resistive relations. In the Summer Story, we find every-day forms of what physicists call resistive or flow relations (see Table 5). We enable heat to flow, we let it flow, or we block it from flowing; we make it easier or harder for heat to flow. In science, the reasoning behind this language is used to introduce measures of how easy or how hard it is for heat to flow (so-called conductances or resistances). It is important to let little children experience situations where heat is let flow or blocked from flowing, and to introduce them to good language for dealing with the situation at hand. As the students get more mature, this is again a case where they can evolve from using qualitative reasoning to applying semi-quantitative or even fully quantitative relations.

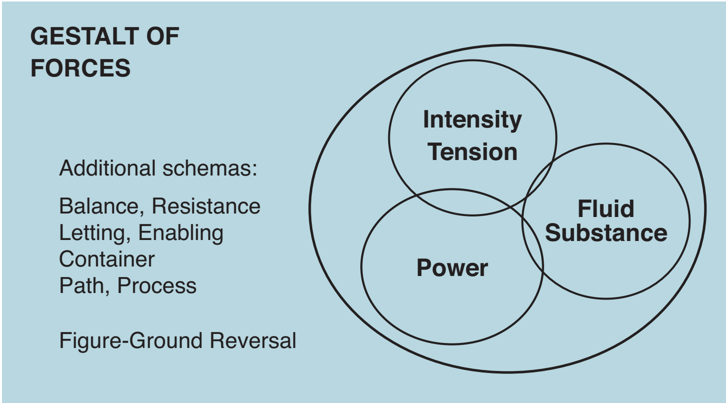

Figure 2: *Structure of the gestalt of forces*. Note that we use a number of additional image schemas in addition to tension, quantity, and power to structure the Force Dynamic Gestalt.

The language of capacitive relations. Capacitive relations have to do with storage of heat and the relation between how much heat there is in a material and how hot it is because of it. The relation is a case of the metaphor MORE IS UP. Remember the implications of the container schema that were discussed in Section 3. As we can infer from the examples in Table 5, there are many cases in the Summer Story of direct or implied language dealing with the observation of storage of heat. (The remarks made above for talking about flows apply equally to the examples of storage of heat.)

Table 5: Some aspects of resistive and capacitive relations in language

RESISTIVE	DIRECT	*…telling his friends that the soles of his shoes did not let the heat of the stones get through.* *The windows of their home were left wide open to let the heat that had settled in the street below into their apartment.* *The huge thick walls of the old building had kept the heat out even after so many days of terribly high temperatures. She was sure that the heat in the streets had tried to get into the building just as it did at home. She wondered if their apartment got so much warmer so much faster because the heat had an easier time to sneak through the thinner walls of their building.*
	IMPLIED	*Anna and Luca remembered that a few days before they still had to wear pullovers. It just was too cold.*
CAPACITIVE	DIRECT	*The air from the street was so hot during the day that it brought with it huge amounts of heat that would be left in their home.*
	IMPLIED	*the grass of the fields and the water of the nearby pond had been swallowing up the light of the Sun making them slowly get warmer.* *…they were surprised that [the water] was still fairly cold.* *…where a huge gush of really hot air came out of the side of the bus.*

6. Evolving the Structure of Stories

In Section 2, I have argued that a story involving forces of nature makes use of two large-scale schemas: *story schema* and *character schema*. The character schema is the schematic structure of a force of nature (derived from the organization of the FDG). It deals with the intrinsic aspects of a particular force. In the Summer Story, heat is a character or agent subject to the character schema. Let us now discuss how a change of emphasis from story schema to character schema can support the evolution of scientific understanding in the child. This means that we have to move from designing and analyzing a single story to focusing upon a sequence of stories that can support this evolution.

From mythic to romantic and formal understanding: Tools of literacy. Remember the brief discussion of theories of the evolution of the human mind (Fuchs, this volume). For our purpose, the suggestions of Donald (1991) and Egan (1997) are particularly important and useful. Like other authors, Donald and Egan propose a stage called *mythic culture* shaped by oral language and it's tools of meaning making. Donald goes on to show how the modern *theoretic mind* grows with the acquisition of literacy and later technological forms of writing (from printing to computers). Egan adds a step between mythic and theoretic forms of reasoning—the *romantic* phase of early literacy (Egan, 1990). Briefly stated, what is most important to us for our understanding of ontogeny, during this stage—said to develop roughly between the ages of eight or nine and about fifteen—children's minds open up to reality, i.e., to the multitude of things and phenomena of the outside world.

Let me stress this point of the emergence of interest in the rich details of reality as a child enters third or fourth grade. A younger child does not have the mental means to deal with, nor the interest in, concrete facts, at least not in the sense of these facts being of intellectual concern. A young child is an abstract thinker, not a concrete or formal thinker. Concrete facts about the world are added later and the ability to use formal reasoning develops later in life as well. A child has abstract schemas at its disposal and it sees the world in terms of these abstractions. In the earliest years in school we should not bother children with details of reality. However, as they learn tools of literacy and become able to deal with lots of concrete facts we should definitely add more and more details to our stories.

This move will be accompanied by a growing sense of and power to use literacy and its forms of understanding (see Di Martino, this volume, and Egan, 1992). Whereas story telling is a result of orality and the mythic mind, full-grown science derives from the power of literacy and formal languages. Evolving the character of forces of nature in our stories naturally involves an increasing sense of reality and the maturing use of formal reasoning and tools that support these abilities.

When children are around eight to nine years old, their minds slowly develop a form of understanding called *romantic* (Egan, 1990). Some important tools evolve with the increasing ability to use literacy such as list making, creation of categories and hierarchies, manipulation of text, graphing, mapping, etc. Children become interested in and capable of dealing with accumulating information concerning the outside world. While list making and categorization support the growth of our understanding of details of reality and help us with the ever growing number of elements of the world we become aware of, mapping engages our mind with explaining what we see in terms of complex and dynamical relationships (note the feedback loops in systems maps; Fuchs, 2002; Roadmaps, 1990). Mapping and graphing take center stage in the sciences because they allow us to focus upon large amounts of information and relationships simultaneously—they represent an interesting case of amalgamation of romantic and formal cognitive tools.

The change of cognitive abilities of children may also be seen in their drawings which move from abstraction to realistic detail. This opens up avenues for illustrating stories where we use abstract and fantastic representations early and then change them into more realistic ones including photographs.

From story to character schema. Let us now discuss the evolution of the design of stories in more detail. In our first stories for the youngest of our students, we put emphasis upon what is called the story grammar or story schema (Mandler, 1984) with its typical affective power, i.e., the power to engage affective understanding. Egan (1986, pp. 96-102) has described in detail how this may be achieved in science class. By choosing the polarity HEAT AS HELPER <–> HEAT AS DESTROYER over HOT <–> COLD for a unit on heat we engage young children's ability to understand affectively and so open a door for them to approach nature.

As you have seen in the Summer Story (or in the Winter Story, Fuchs, 2010a, and this volume), there is no harm in introducing at the same time the characters of cold or heat with their aspects that later become central in the sciences. It makes sense that these characters are not completely developed in early stories, but they are present. This leads us to a simple idea for how to evolve narrative in science education: we can let the characters of forces of nature with their schematic structure step from the background into the foreground (Figure 3). This means that we can and should take the liberty of slowly changing the form and content of stories from a typical one to more formal narratives.

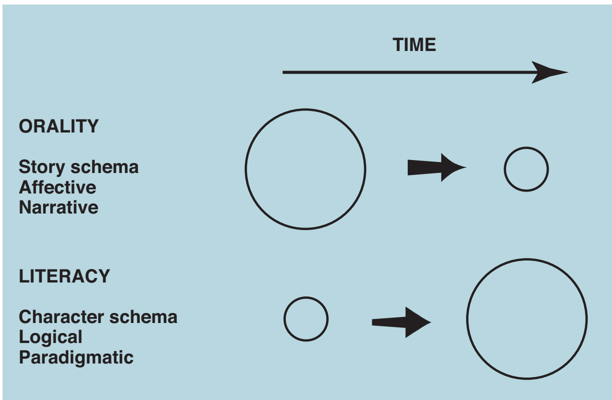

Figure 3: Evolution of the relative importance of *story schema* and *character schema*. In the beginning of education, we place more emphasis upon the typical story schema with its affective power and less upon the character schema that lends itself to formal development. Over the course of time, the relative importance of these schemas is reversed.

One possibility for letting the intensity of human concerns decrease is to replace humans as actors by nature itself and showing that it is shaped by its own forces. This means that a child learns to get affectively engaged with nature. Examples of such stories can be easily found in the evolution of the physical, chemical, and biological systems ranging from the universe through galaxies and stars to the Sun and planets and finally to the surface of our planet with its geological and life-forms. Take as an example the opening lines of Sadi Carnot's *Reflections on the Motive Power of Fire* (Carnot, 1824):

> *To heat also are due the vast movements which take place on the earth. It causes the agitations of the atmosphere, the ascension of clouds, the fall of rain and of meteors, the currents of water which channel the surface of the globe, and of which man has thus far employed but a small portion. Even earthquakes and volcanic eruptions are the result of heat.*

This is a statement of romantic sentiment (remember that Carnot worked toward the end of the modern period of romanticism). It talks about the fascinating phenomena of the world out there, it brings up a multitude of aspects of reality—much more than one would expect and need in a book that concerns itself with the development of a formal theory of heat. Talk of the forces of nature is embedded in a long list of phenomena that should interest us. This is an example of how our involvement with nature can be used to usher in the romantic phase in our students (see Egan, 1990). Getting affectively (romantically) involved with nature and human made artifacts may be what is necessary to turn a child's attention from human affairs to the affairs of nature and engineered objects. Developing romantic understanding thus complements the introduction of formal explanations of how the world works.

Let me repeat this point. I believe that romantic and (early and simple) formal thought develop jointly during the later years of primary school. The subject of energy serves as a point in case. The idea of energy in natural processes has its origin in the early nineteenth century as a romantic concept. At the same time, at the hands of scientists it has always been dealt with as a formal construct. We can use our observation of the historical development of the energy concept for the design of science pedagogy: we let our stories of forces of nature evolve by applying the story schema to nature and the development of industry, bringing in more and more concrete details of the world out there, and turning the narration of the character schema slowly into linguistic representations of models of how the world works. All the time we make increased use of the tools of literacy—list making, creation of categories and hierarchies, manipulation of text, graphing, mapping, etc.—and of the formal language of mathematics.

7. Summary: Teaching Science for Primary Understanding

I have argued the case for the design and use of stories in science education in primary school. Stories are not just useful for embedding science in the larger world of human concerns. They can be created to narrate the character of forces of nature. In such stories, we can learn how characters such as heat or cold, electricity or water, air or fuels, behave and make the world work. Remember that the goal of all of this—from the viewpoint of the physical sciences—is the conscious and complete differentiation of the schemas of the Force Dynamic Gestalt and the ability of a young person to reason qualitatively and quantitatively with these schemas and their relations.

If we use not a single story but an evolving sequence of narratives, we can help children to become affectively engaged with nature itself. This will support the introduction of aspects of reality that become of greater concern to them as they get older. We make increased use of the tools of literacy so that children learn (1) to deal with the bewildering diversity of nature and of (industrially) created objects and (2) to explain phenomena by creating narrative forms of models of natural systems and processes.

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