FROM MYTHIC THOUGHT TO AN UNDERSTANDING OF NATURE

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Abstract. In this talk, I will continue the theme of the schematic and narrative structures of the human mind that I started two years ago at this conference (Fuchs, 2010a). Today I would like to discuss the development of science beyond mythic thought and its consequences for science education. I will review the idea of the mythic basis of our perception of forces of nature, talk about some examples of mythic structures in science created through the centuries, and then ask what it takes to create modern science. The following three aspects are identified as being crucial for the development of an understanding of physical science: romantic realism, theoretic thought, and the concept of space. I conclude that story telling should be continued as an important tool for learning and can be evolved into more formal narratives for the task of creating models of natural processes. Stories can be used to deepen our understanding of the gestalt of forces and its aspects while helping to motivate a romantic engagement of the human mind with nature. Tools of theoretic thinking are best developed in a narrative approach to model building. The concept of space is an expression of the growing distance between the experience of self and its unconscious. We need to know this if we want to understand the meaning of microscopic models vis-a-vis models of forces of nature.

1. INTRODUCTION

Exactly two years ago, at our first conference here in Modena, I presented a description of schematic, metaphoric, and narrative structures in human thought in general and in physical science, in particular (Fuchs, 2010a). This, I suggested, should help us design good stories for science teaching in early childhood (see also Fuchs, 2012a,b; Corni et al., 2012).

The idea is pretty simple: If it is true that the same schematic and metaphoric structures are found in everyday descriptions of our world as well as in science, we can hope that a narrative approach to science is possible and teachers should find it easy to become good storytellers about the *forces of nature* such as heat, light, chemicals, water, air, soil, electricity, motion, or food (Corni et al., 2012); in other words, the things that determine much of what goes on around us. Indeed, we find that the language of young children is already full of the structures that can be turned into a more formal science later in life.

All of this is not so surprising if we realize that human language and human thought are figurative, that image schemas which develop early in life are used in metaphoric thought, and that we all tell stories to make sense of the things and processes around us. If we believe, however, that science is to be taken as a literal expression of truths outside the human mind, we will find it difficult to think of a science that can satisfy children and scientists alike.

In this talk today I would like to enter a little more deeply into the world of physical science and trace fundamental concepts by outlining some of their historical development. I will do this by following human conceptualizations of nature all the way from oral mythic cultures to modern continuum physics to demonstrate that the roots of science today are old and biologically and culturally well founded. This also means that you do not have to be afraid that I will launch into a formal discussion of theories of modern science: Everyday language provides us with the tools needed to understand what I would like to say. At the end of this talk I hope to outline some practical ideas for science education.

I am doing this for at least two reasons. Firstly, we should be convinced that mythic thought is indeed a source of understanding of nature in all of us and that it creates the foundations of modern science. Secondly, by looking at its development we may discover what is needed beyond mythic thought to create science. This is important for the purpose of this conference where we would like to discuss paths that lead from early childhood education to science learning for the second part of primary school and beyond. The urgency of this task is grounded in the observation that the mind of a child starts changing profoundly around the ages of eight to ten (Egan, 1990, 1997). What does this mean for education in general and for science education in particular?

2. Mythic Thought and Early Cosmologies

When we observe how small children play, interact, and talk, we cannot escape the feeling that they live in a world different from that of the adults, a world not unlike the one we find recounted in the myths of bygone times.

It is the world of oral cultures (Ong, 1982) that still exists in some pockets of humanity (Levi-Strauss, 1968; Parry, 1971) and that is recreated in "societies" of children between the ages of about four and eight or nine (Egan, 1988). What we normally do not know is that the abstractions that populate the world of our children are the same that create the conceptual basis for the macroscopic theories of forces of nature. So let us take a look at how humans have described and explained the workings of nature through the centuries and millennia.

Before I say a few more concrete things about early cosmologies and creation myths, it is important to note that what is passed down to us in the myths of ancient cultures represents a depiction of the development of the human psyche (see, for example, Neumann, 1949/1954).

What we experience in ourselves—our psychic experience—is projected outward onto the world. Our most basic archetypes are used to structure our myths of the world.

While details vary, there are some important common traits in the cosmologies of ancient cultures such as the Sumerians, Egyptians, or American Indians (Levy-Bruhl, 1923/2012, 1926/1985). Typically, the world begins as an undifferentiated whole. Then, in Sumerian cosmology, for example, the wind separates heaven from earth, letting the sky arch over the disk of the earth. In Egyptian myth, after the first differentiation of the primordial waters, earth and sky still form a tight unity which is later separated by the god Shu (air) intervening between Geb (earth) and Nut (sky; see Fig. 1). Importantly, earth and sky are thought to be solid—they separate the primordial waters. The sky is sometimes considered to be made of metal, sometimes of crystal. The world of the ancients is finite; there is no modern sense of the heavens being an expanse of air or just infinite and empty space (Seely, 1991). *Space* as an abstraction did not exist (Weber, 2006)—this point will become important later when we consider modern forms of science.

Figure 1. Shu supports the sky (Nut) from falling back onto the earth (Geb). This is a typical image depicting elements of ancient Egyptian cosmology.

Basically, all creation myths speak of the becoming of the world as a process of separating of *qualities* such as light and dark, high and low, wet and dry, hot and cold, day and night, dream and waking. Here we have the source of an important form of mythic understanding: our sense of *polarities*. The human psyche and our societies know polarities such as good and evil, courage and cowardice, justice and injustice, friend and foe. We may very well consider these binary opposites (Lévi-Strauss, 1969) driving forces of what we see happening around us. They are basic structuring elements of the stories we tell our children and ourselves.

There is a second pervasive form of thought known throughout human history, the notion of *agency* (Gell, 1998). There are not only human agents. Agency is ascribed to *objects* and unseen things which we might call the ghosts behind appearances. As Miller (2012) put it in a modern context, “Where material forms have consequences for people that are autonomous from human agency, they may be said to possess the agency that causes these effects.” Agency has two important aspects, that of *object*, thing, or person on the one hand, and that of *causation*: the agent causes something to happen, does something to something or somebody else.

The perception of qualitative distinctions, i.e., polarities, and the sense of agency curiously combine to form a whole. We do not only experience the qualities of light and dark, we create the concepts of light and darkness as agents that cause things and have the power to influence things in this world. We will rediscover the notions of *quality*, *object*, and *causation* in the natural sciences that have been created since the waning of mythic cultures and the dawn of what we call the modern world.

Let me add one more thought at this point. Even though we are accustomed to assume that science requires a mature mind well trained in formal methods, the notion of mythic understanding of nature should not rattle us. Basically, modern humans are equipped to survive on this planet if they use the cognitive tools of oral culture which every healthy individual growing up in a community will learn. Being able to do science is not the same as understanding nature—the latter is a simple biological requirement. It is just interesting to see that the biological requirement also provides us with the cognitive tools that are the stepping stones for building formal sciences.

3. Early Science to Modern Continuum Physics

In this section, I will briefly review some examples of physical science through the centuries and point out conceptualizations that obviously draw upon mythic thought. I do not and cannot strive for any form of completeness in this description. Afterwards, in Section 4, I will discuss aspects of modern science that go beyond mythic culture. Even though I would like to stress that many of its basic concepts are ancient, physics is thoroughly modern in its practice, formalism, and outlook.

Let me begin with *Hero of Alexandria* (10-70) and his *Pneumatics* (Woodcroft, 1851) and quote just a few short passages. Hero gave a short introduction to what may be considered the background of his science and engineering and then briefly described a large number of devices that make use of air, liquids, and fire to create useful and amusing effects. He writes that "[…] by the union of air, earth, fire and water, and the concurrence of three, or four, elementary principles, various combinations are effected, some of which supply the most pressing wants of human life, while others produce amazement and alarm." On the subject of vacuum, we hear that "Some assert that there is absolutely no vacuum; others that, while no continuous vacuum is exhibited in nature, it is to be found distributed in minute portions through air, water, fire and all other substances […]. Again, that void spaces exist may be seen from the following considerations: for, if there were not such spaces, neither light, nor heat nor any other material force could penetrate through water, or air, or any body whatever."

After the Introduction, from where these quotes were taken, Hero describes devices, very often without giving any further reasoning for why they work. He makes a drawing of a machine, labels important points and gives a detailed description of how to build and operate it. We have here some of what I would call mythic reasoning, for example in the title for Section 77 "An Altar Organ blown by the agency of a Wind-mill" and when he continues to say that "When all of these arms, urged by the wind, drive round the wheel […]." Or in Section 11, "Libations at an Altar produced by Fire […] The pipe through which the heat is to pass should be broader towards the middle, for it is requisite that the heat, or rather the vapour from it, passing into a broader space, should expand and act with greater force.”

Hero clearly uses mythic concepts to argue why nature works the way it does. However, there are already some elements visible in this account that would not have been possible in a mythic society. We will see what they are in later sections of this essay.

Now we take a step to 17th century Florence where a group of experimenters founded the *Accademia del Cimento* (Magalotti, 1667). They performed experiments on air, heating and freezing, magnetism, electricity, light, and more. Above all, they tried to describe and understand the various *forces of nature*. One section of their book deals with the force of cold (Fig. 2). Here are some of their words with which they introduced the section on *Experiments on Artificial Freezing* (Waller’s translation of 1684 in Magalotti, 1667, pp. 69-70):

> *Among the rest of the stupendious Works of Nature, that admirable Power has been always much regarded, whereby she binds the slippery Waves, changing their fleeting Inconstancy into Solidity and hardness. […] Cold […] stops and consolidates the most Fluid Liquors, changing them into downy Snow, and glassie Ice […]. And (which is yet more amazing) so violent a force of Cold in Freezing, is observed penetrating not onely Glass, but even the secret Pores of Metals. […] Cold in the Act of Freezing cracks shut Vessels of thick and strong Glass; stretches, distends, and at last, tears those of pure Gold, and bursts asunder those of Cast Brass; […] Some have thought, that where the Cold operates in its proper Laboratory with fit materials, it reduces the pure Water to such a temperament, that it turns it into even the hardest Rock-Cristal, […].*
>
> *But to return to the Causes of Freezing. The ingenious in all times have had various Sentiments thereof: whether it does indeed come from any real and proper body of cold […] that (as Light, and Heat are Originally in the Sun) is either in the Air, or Water, or Ice it self; […]*

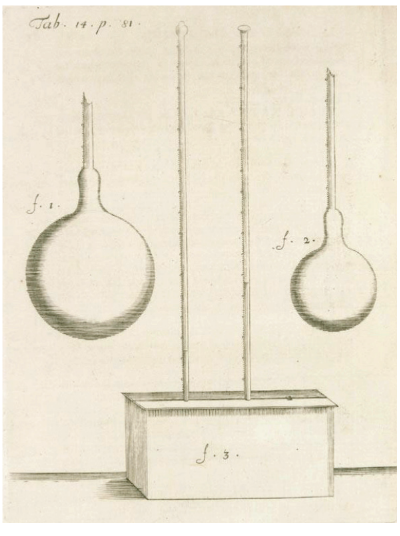

Figure 2. Drawing of an apparatus used to investigate the force of cold, from the book of the experimenters of the Accademia del Cimento. One bulb was filled with alcohol and served as a thermometer, the other contained the liquid to be frozen.

Again, we find the elements of mythic language describing forces of nature in terms of quantity, intensity, and power or force. The schematic aspects of this ubiquitous form of language and thought are present but not necessarily well differentiated. It took another 150 years before a view emerged where the aspects of the gestalt of forces were clearly distinguished. This was achieved by *Sadi Carnot* in his book *La Puissance du Feu* of 1824. In his words:

> *According to established principles at the present time, we can compare with sufficient accuracy the motive power of heat to that of a fall of water … . The motive power of a fall of water depends on its height and on the quantity of the liquid; the motive power of heat depends also on the quantity of caloric used, and on what may be termed, on what in fact we will call, the height of its fall, that is to say, the difference of temperature of the bodies between which the exchange of caloric is made. In the fall of water the motive power is exactly proportional to the difference of level between the higher and lower reservoirs. In the fall of caloric the motive power undoubtedly increases with the difference of temperature between the warm and the cold bodies; but we do not know whether it is proportional to this difference.*

Carnot's description of forces of nature serves as the archetype for my further exploration of physical science (Fig. 3). It is expressed in the clearest of forms using the power of analogical reasoning made possible by the figurative structures of the human mind (Fuchs, 2006, 2007, 2010b). The concepts are mythic. The resulting theory of the power of heat is modern, i.e., it unites mythic understanding with the elements that make modern science possible. We will say what they are in the next section.

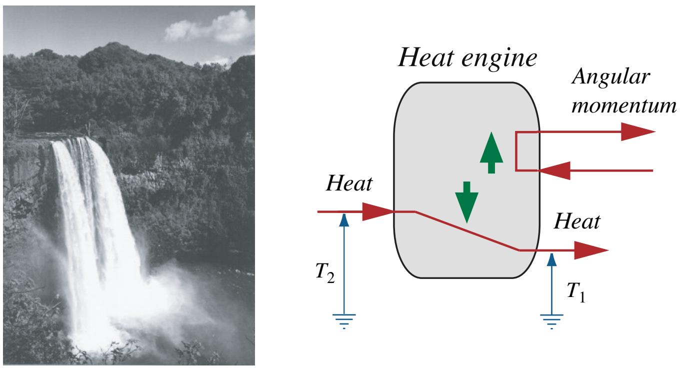

Figure 3. A waterfall serves as the archetype of a physical process. In a voluntary (spontaneous) process, a quantity flows from a higher to a lower level (it is driven to flow by the level difference). In so doing it drives other processes, i.e. it creates a new level difference for the following process. We say that energy is needed to do this. The energy is provided by the fall of the quantity from a higher to a lower level.

One hundred and fifty years after Carnot's work we find modern theories of *continuum physics*. When we explore language and structure of the usually completely formal and mathematical treatments, we again find the same mythic concepts at their core (Fuchs, 2010b). A continuum model of, say, the flow of electricity through a conducting material, begins with a statement of what is called the law of balance of electric charge. This is just the mathematical form of our belief that electricity has a quantitative aspect that is best described using the analogy of a *fluid substance*: electricity flows and is stored as if it were a fluid, a special fluid but a fluid nevertheless. Then there is the notion of the *intensity* of electricity, sometimes called electric *tension* (I am using the word tension in place of the technical term voltage). The electric tension itself is the result of how densely electricity is packed inside a material. A tension between two points in the conducting body lets electricity *flow*. By itself, it flows from where the intensity of electricity is higher to where it is lower, hindered only by how strongly the material *resists* the transport of electricity.

As electricity flows through a conducting material, it causes other things to happen. It can pump heat or produce heat, it can produce light or change the chemical makeup of the material. Electricity has the power to effect these changes—which in turn can produce other changes. Conversely, electric processes are caused by various other changes having to do with light, chemistry, heat, or motion. All these couplings are quantified by what physicists have come to call *energy*. Mythically speaking, we can think of energy as the measure of the power or force of a phenomenon (Fuchs, 2010b, Chapter 2; Fuchs et al., 2011).

There is another example in the history of physics that is of great interest to our inquiry: the development of theories of planetary motion, from Plato and Ptolemy to Copernicus, to Kepler, and on to Newton. The story is often recounted as an example of the mathematical—or rather geometric—description of patterns in space and time. Interestingly, however, progress in creating theories came from a re-introduction of mythic concepts. Originally, in Ptolemy's science, explaining, or rather calculating, planetary motion was an exercise in pure geometry inspired by Plato's philosophy. Copernicus introduced his strong belief that this was not an explanation at all, that it did not address the question of the true nature of the solar system. Surely, God would have created the world and humans so that we could recognize the true nature of reality (Blumenberg, 1965). He thought that the heliocentric model would be such a true description. In concrete terms, however, Copernicus' model did not part from the geometric approach of his predecessors. The planets were assumed to move along circles with the sun placed somewhere inside the circle—the precise location determined by purely geometric considerations. This, it turned out, made calculations less reliable than those of Ptolemy.

A far reaching change in the model of the solar system came with Kepler who maintained that the motion of the planets could not simply be understood on geometric terms but had to be a result of the physical influence of the sun upon the planets (Koestler, 1959/1990). Newton managed to give an account of planetary motion which satisfies Kepler's notion and our modern view of physical science. Curiously, the basic concepts of motion were again mythic like all the others I have been telling you about so far. Motion is described in terms of *quantity of motion* (momentum) which is added to or taken away from bodies. Moreover, motion has an *intensive* aspect—speed—and it is clearly endowed with *power*.

After all these examples, we can confidently claim that science is mythic at its roots. But what about the rest of the tree?

4. Science Beyond Mythic Thought

Mythic thought is a necessary ingredient of science but does not suffice alone for constructing it. When you inquire about what came after the mythic phase, different aspects are emphasized depending upon whom you ask. Psychologists will tell you that the sense of self grew stronger in the course of the last few millennia, sociologists and historians point out that the structure of human societies changed and technology made its way into our lives, and linguists and scholars of cognitive and social evolution stress the importance of the transition from orality to literacy and the accompanying technologizing of the word. Most likely, all of these processes are somehow involved in the development of science beyond mythic understanding and it will be difficult to point to one in particular as the sole cause of all the changes. In fact, it makes more sense to see these aspects as somehow related and mutually reinforcing factors.

Sadi Carnot can serve as a perfect example of this. If we read a few more paragraphs of the introduction to his book (1824), we get a clearer view of a developing scientific mind:

> *Every one knows that heat can produce motion. That it possesses vast motive-power no one can doubt, in these days when the steam-engine is everywhere so well known.*
>
> *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. […]*
>
> *The phenomenon of the production of motion by heat has not been considered from a sufficiently general point of view. […] A [complete] theory is evidently needed for heat engines. We shall have it only when the laws of physics shall be extended enough, generalized enough, to make known beforehand all the effects of heat acting in a determined manner on any body.*

Sadi Carnot's understanding is *mythic*—remember his explanation of how heat engines operate—and *romantic* and *theoretic* at the same time. Witness his romantic interest in nature and in employing its power in the art of engineering, and his desire to create a general and formal theory. I follow Egan (1990) and Donald (1991) in calling stages of understanding that follow the mythic phase *romantic* and *theoretic*. Copernicus' belief in our power to recognize the true nature of the world is romantic. Kepler's idea that it is the force of the sun that makes the planets move the way they do, and Newton's concept of momentum, are mythic; and their process of building mathematical models is theoretic.

Here are some aspects that characterize science. We have become interested in the rich detail of the material world and have been awed by its sheer beauty or terror at times. We have learned to employ forces of nature for social and economic ends by creating machines that apply these forces. We use lists, maps, and diagrams; we quantify, measure, and experiment; we use mathematics as a language and Java to make computers work in our scientific enterprise; we think in terms of relationships, processes, structures, and systems; and all of it is described and collected in books that fill our libraries and the Internet.

One element is missing from this list which would seem so natural in this age of space travel: the notion of *space*. It is a romantic notion with great theoretic consequences that will be discussed below and in Section 6. Remember that mythic cosmologies did not include any abstract notion of space. There is a slight reference to space in Hero's Pneumatics, and it plays an important role in the theory of planetary motion following Copernicus' lead. (We might even say it was created as a consequence of the development of astronomy, but note the discussion of psychological forces below.) Human understanding broke through the firmament (Fig. 4) and the sky became a vast, empty expanse: the modern notion of space was born. It is such a ubiquitous element of our modern understanding of ourselves and of astronomy and microscopic physics that we are taken aback when we realize that little children do not naturally make use of this concept.

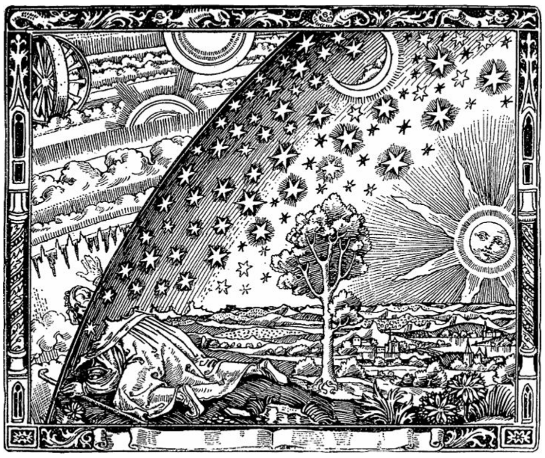

Figure 4. A wood engraving by an unknown artist depicting the penetration of the firmament. It first appeared in Camille Flammarion's *L'atmosphère: météorologie populaire* (1888).

Now I am ready to summarize what I consider the most important general characteristics of modern science:

1. *Romantic realism*: a sense of an independent outside reality that can be listed, mapped, measured, and experimented with, and an interest in its beauty and rich detail.
2. *Theoretic thinking*: a sense of the independent reality of formal thought, an interest in the power of logic and theories, and a belief in laws of nature.
3. The concept of *Space*: the abstraction of (empty, dark, infinite) space.

How did these notions and concepts arise? It is clear that they grew in parallel with literacy and it makes sense to claim at least some causal force on the part of the techniques of writing. Mythic culture developed in oral societies; the mythic mind is a product of orality even today (Ong, 1982; Egan, 1988). Science, on the other hand, is definitely a child of literacy and its techniques that include formal languages (e.g., mathematics), the printing press, and the Internet (Ong, 1982; Donald, 1991). Without the tools of literacy we would not have the means of listing, mapping, measuring, and graphing the sheer infinite diversity of material reality; we would hardly have the means for experimenting.

This, however, is only half the story. Another driving force, which interacts with the first, is psychological: it is the experience of *self* that grows as consciousness develops—both historically and in the individual. This feeling of the independence and power of my own mind or my own soul—the self vis-a-vis an outside reality—is the result of an increasing distance between self and its unconscious (Neumann, 1949/1954; Weber, 2006). This distance is responsible for the sense of the reality of the outside world and the products of theoretic thinking, and is reflected in the historically recent abstraction of infinite, empty space.

We have good reason to believe that humans in mythic cultures and today's young children are closer to their unconscious (Weber, 2006). Something important must have changed in the modern mind. Francisco Petrarch presents us with a beautiful example of how a romantic feeling for the reality of the outer world combines with a concept of space. In his letter to a philosophy professor he writes (Petrarch, 1336/1948):

> *Today I ascended the highest mountain in this region, which, not without cause, they call the Windy Peak. Nothing but the desire to see its conspicuous height was the reason for this undertaking. […]*
>
> *The day was long, the air was mild; this and vigorous minds, strong and supple bodies, and all the other conditions assisted us on our way. The only obstacle was the nature of the spot. We found an aged shepherd in the folds of the mountain who tried with many words to dissuade us from the ascent. He said he had been up to the highest summit in just such youthful fervor fifty years ago and had brought home nothing but regret and pains […] While he was shouting these words at us, our desire increased just because of his warnings; for young people's minds do not give credence to advisers. […]*
>
> *And now […] listen also to what remains to be told. […] At first I stood [at the summit] almost benumbed, overwhelmed by a gale such as I had never felt before and by the unusually open and wide view. I looked around me: clouds were gathering below my feet […]. The Alps were frozen stiff and covered with snow […]. They looked as if they were quite near me, though they are far, far away. […]*
>
> *Then another thought took possession of my mind, leading it from the contemplation of space to that of time […] I had better look around and see what I had intended to see in coming here. […] The sun was already setting, and the shadow of the mountain was growing longer and longer. […] I turned back and looked toward the west. […] one could see most distinctly the mountains of the province of Lyons to the right and, to the left, the sea near Marseilles […]. The Rhone River was directly under our eyes.*
>
> *I admired every detail, now relishing earthly enjoyment […] I was completely satisfied with what I had seen of the mountain and turned my inner eye toward myself. From this hour nobody heard me say a word until we arrived at the bottom.*

This is an important passage testifying to a new element of the modern mind: *romantic realism* and *the abstract concept of space*. Without this development we would not have modern science and we would not have—starting some 500 years after Petrarch—the overwhelming feeling that reality lies in the motion of little particles in empty space (see Section 6).

Then there is theoretic culture. Again, without literacy, we would not have the technical means for developing mathematical theories. Still, it seems we need psychological developments as well to create theoretic thinking. On the one hand, there are the tools for formal, logical thinking, on the other there is the growing sense of reality of the thinking self and the products of its thought. It seems that the development of the sense of self—whether by technological means including those of literacy or by natural development of the psyche—is a key to understanding the development of modern science beyond its mythic roots.

5. Science Education Beyond the Earliest Years

Two years ago I argued that understanding of nature (and of ourselves and society) is based on mythic concepts that develop early in history and very early in the life of a child. From the perspective of cognitive linguistics, our mind constructs forms of understanding based upon *image schemas* and their *metaphoric projections* (Lakoff and Johnson, 1999; Hampe, 2005). [Image schemas are abstract structures created from our bodily interaction with the world that start to develop right with the beginning of life; Johnson, 1987]. Since then, Federico Corni, Enrico Giliberti, Cristina Mariani, and I have created a narrative approach to science learning for the first few years of primary school (Corni et al., 2012), and we have argued that teachers can become confident narrators of stories about natural forces which small children can understand, love, and profit from.

This argument is well developed and strong enough for building early science education upon. Today, at this conference, we are ready to go beyond this and consider the consequences of the outline of structures of science I have given so far. There are some important consequences for our understanding of the development of the mind of a child beyond the first few years of primary school, and for education.

Let me introduce a graphical representation of how we think the development of the mind of a modern human proceeds (Fig. 5). During the early years, when a child learns to master spoken language, his or her mythic mind arises and the power of mythic understanding grows (Egan, 1988). The subsequent developments of romantic and theoretic understanding do not take place in a neat succession of steps. Rather, they proceed in parallel and interact, at least to some degree. When a human is given the opportunity to change beyond the mythic stage—aided by the grasp of literacy—both romantic and formal kinds of understanding become possible almost simultaneously. If the mastery of reading and writing and the simple biological, emotional, and social effects of growing up combine to let the experience of self arise, the development of the senses of the independent reality of the outside world and of formal thought, and the concept of space become possible. There is a constant interplay and mutual reinforcement of romantic and theoretic forms of understanding.

Most importantly, the figure (Fig. 5) suggests a feedback loop between the developments of romantic and theoretic thinking and mythic understanding. Romantic and theoretic tools do not just grow out of the mythic base (and leave them behind), they are constantly informed by mythic tools of understanding. Conversely, differentiation of the elements of the gestalt of forces (FDG) becomes possible due to us becoming more conscious of these basic structures because of their application in romantic and theoretic forms of science. As a result, mythic forms of understanding become better grounded. This last point is important: Even though the schematic structures of the FDG are common sense, their use in precise arguments and in science do not follow automatically. They will be a result of education.

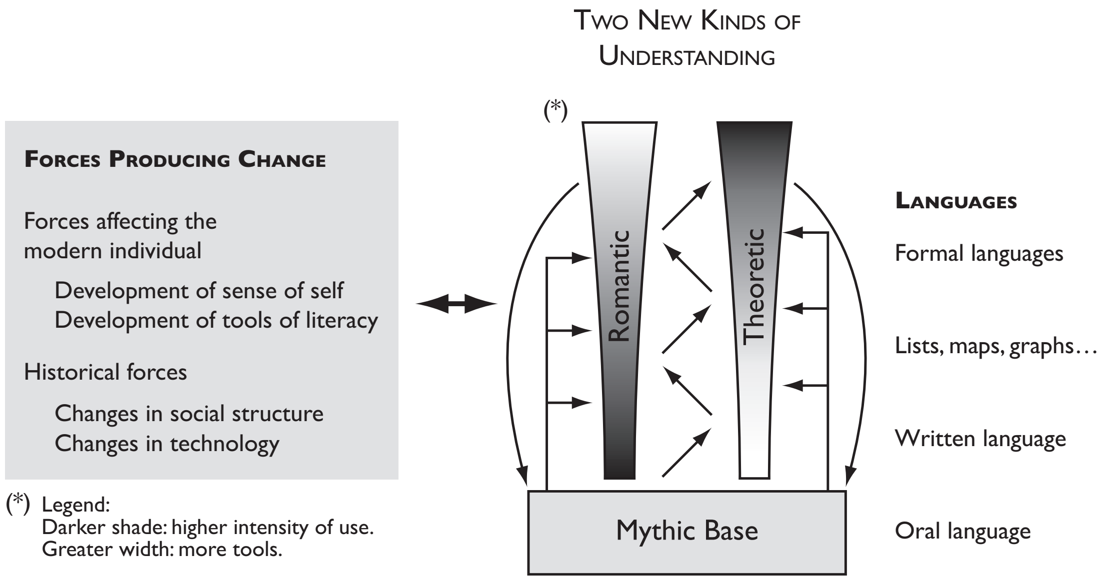

Figure 5. A model of growth of romantic and theoretic forms of understanding. Romantic and theoretic cognitive tools grow on the basis of mythic culture. The number of sense-making tools increases in time for both forms of understanding. The intensity of romantic thought is assumed to be stronger earlier. However, both forms seem to grow in parallel as mutually interacting and reinforcing powers. The mythic base constantly informs the growing tools of romantic and theoretic thinking which, in turn, help in making the structure of mythic understanding conscious.

The view outlined here is well supported by historical developments. In the course of the last two to three millennia, there have been several phases of romantic and theoretic thinking (Egan, 1997). There have been romantic phases in Greece (Herodotus), during the Renaissance (Petrarch and Copernicus), and during the the phase we properly call Romanticism that coincides with the industrial revolution and romantic Naturphilosophie (natural philosophy). There have been pronounced phases of theoretic culture, in Greece (during the age of the philosophers and mathematicians), in Arab culture, in Europe in the late middle ages after the rediscovery of the Greek philosophers, or later with Kepler and Newton and their successors who created mechanics. Remember that all the time, mythic concepts were re-surfacing or were re-introduced and combined with the powers of the modern mind.

This is not to say that there could not be a certain natural sequence for cognitive tools to emerge in a child. In history, Herodotus came before Thucydides, the general and historian who wanted to explain the structure and causes of war rather than just recount everything that was strange, wonderful, or memorable; romance came before theoretic culture. There is much to say about this course of events in the development of our minds: romantic understanding comes before we develop the sense of the reality of theoretic constructs (Egan, 1997).

The tools of literacy are introduced before romantic realism, theoretic thinking, and the concept of space emerge. Children learn list making, mapping, graphing, and numeracy before their sense of self is strong enough for them to become romantically engaged with a richly diverse reality and before they become interested in theories of motion, electricity, or heat. Still, we should be careful about neatly dividing the years of late childhood and adolescence into two clearly separated consecutive phases. With today's education in mathematics and the availability of computing and modeling tools, some formal developments—precursors of theoretic constructs—become accessible relatively early in the life of a child. Even without these, there is bound to be a constant back and forth between parallel lines of development.

What does all of this mean for science education after the first few years of school? In general terms, the answer is fairly simple: we need to give children the opportunity to develop romantic and theoretic understandings of the world. The difficulty lies, as always, in the detail.

Let me again turn to story telling and narrative approaches for help. Stories have helped us so far; they are the right vehicle for conveying and working on an understanding of forces of nature early in school. By the time third grade ends, we can expect the mythic mind to have evolved more or less, and children should be able to appreciate elements of the gestalt of forces of nature. However, this does not mean that this path has come to an end: learning to differentiate the aspects of the gestalt as well as in Carnot's account of heat engines takes much longer and is most likely achieved only in combination with a richer knowledge of elements of reality and supported by simple formal thought. Moreover, we should not forget that the gestalt of forces is richer than its three main aspects—quantity, intensity, and power—let us believe: there are additional schematic structures which need to be learned explicitly such as resistance, containment, inertia, paths and cycles, etc.

If we believe in the power of a narrative approach to science learning, we have to try to answer two questions: How can stories be used to learn about the wonderful and rich reality around us, and how can they be employed to support the development of theoretic thinking?

About the first question. It appears fairly easy to create and use stories that awaken and sustain our interest in the world. It is commonly suggested that romantic engagement is fueled mainly by stories of wonderful feats of heroic individuals. This is certainly true, children and young adolescents do react positively to such stories. Personally, I believe that nature provides us with analogous examples of wonderful, scary, important, and powerful characters whose feats are worth telling: the forces of nature. We simply continue our narrative approach to science education and create and use stories of forces of nature that become much more rich in realistic detail and provide teachers and students with material to which they can apply the steadily growing powers of the tools of literacy. Stories of how humans make use of forces of nature in agriculture and industry, and how we try to protect ourselves from the ravages of nature, may be among some of the best examples. Finally, the stories that drive this development in science class can be enriched by well chosen experimental, or generally investigative, themes. Again, strengthening the use of the tools of literacy—list making, mapping, graphing, etc.—is absolutely essential if we want to make progress with experimental science.

Now theoretic thought is a tougher problem. Theoretic thought makes use of formal languages and seems to be hard to fit into a narrative mold. Still, remember what we want to achieve: we want students to learn to use their understanding of the aspects of forces of nature to create models of realistic processes: the heating or cooling of a cup of tea; the decay and dilution of a pollutant in a lake over the course of time; the function of the aorta in the human body; the flow and use of sunlight, maybe by a leaf, or the transport of water though soil and its evaporation at the surface; the motion of a rocket. Everywhere we look, the forces which we understand in mythic terms are at work. The models we want to learn to create are first of all extensions of the stories we have used to learn about the forces. A solid approach to modeling of natural and technical processes proceeds along narrative lines: implicit understanding is narrative; word models that go before formal models are narratives; graphical representations of models building from an understanding of relationships between aspects of a system are visual metaphors projecting the well known schematic structures that appear in our stories—they are stories in picture form. Mathematical representations are only the final step in this line of story telling. By understanding the modeling process as a narrative path we may even learn to read equations as if they were stories.

To make the foregoing discussion a little more real and practical, let me very briefly outline a story which is probably well suited for 10-11 year old children. Two sisters, Sarah and Robin, experience the recent hurricane that hit the North East of the United states. Such a story develops the gestalt of the force of a storm, it makes use of the concepts size, intensity, power, and duration of its raging through the area, and it connects the atmospheric phenomena to heat and cold. Romantic and theoretic aspects are easily embedded and can be used to guide classroom activities geared towards developing these new senses.

Robin and Sarah have heard their president say that “This is going to be a big storm. It’s going to be a difficult storm.” They have access to television and computers, they track the storm, map its path (Fig. 6), collect satellite images of its development and pictures of its impact. They do this during the days schools have been closed as they huddle in the living room, afraid that the storm will damage their home but still excited to be part of something so awesome. When the storm cuts their electricity, the backup power kicks in which their parents had installed recently. They keep busy discussing the relevance of factors such as size, intensity, and duration upon the devastation it causes and come up with semi-quantitative models.

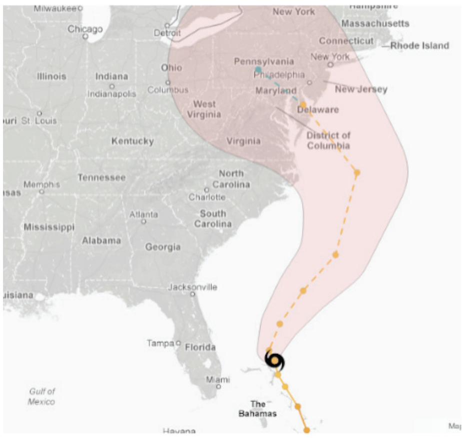

Figure 6. The path of Hurricane Sandy as predicted by meteorologist. The widening shaded cone reflects the imprecision inherent in predicting the actual path.

They hear that the storm’s power is fed by the warm waters of the ocean and that the intensity of the storm decreases fast when it is over land. However, it will meet with the very cold continental air of another storm which will lead to the development of extremely intensive rain and snow fall. They remember what their teacher had told them about heat as an agent and how heat can drive engines and create storms. All of this can be turned into a consideration of the power of heat as the driving agent of the storm.

6. Little Particles in Empty Space

You may have wondered why, in my description of the conceptual basis of physical science, there are no particles roaming dark, empty, infinite space. I have not used what is often considered the cornerstone of a modern realistic description of the material world. The theories I have discussed have been condescendingly called *phenomenological* and their concepts *metaphoric*. Today, when we want to know how the world *really* is and how it *really* works, conventional wisdom tells us that little particles moving through space create what we experience. Never mind that the concept of motion is mythic. Rudolf Clausius, one of the creators of traditional thermodynamics, stood at the beginning of the modern form of this development. In 1850 he wrote (Clausius, 1850):

> *[...] other facts have lately become known which support the view that heat is not a substance but consists in a motion of the least parts of bodies.*

For education in general, and for science education in particular, there are two important problems related to microscopic models of nature: first, children, or rather adolescents, need to be ready for the fundamental abstraction necessary for this picture; secondly, we have to inform students that behind all of this there are still the old mythic concepts—which they obviously should have learned about before. It is simply not true that we gain a privileged form of access to reality by invoking little particles.

Let me start with the first problem. As Weber has pointed out (Weber, 2006), there can be no microscopic physics without the notion of abstract space. As we have seen, this abstraction develops late in history and probably quite late in an individual growing up today. It takes the experience of the distance between the self and the rest of the world, the world that once was the immediate world of parents, friends, siblings, home, food, clothes, rain, wind, the sun, warmth, cold, light, dark, earth, sky, pain, joy, and stories. The experience of consciousness has to be strong enough to create the self as opposed to her world. This distance creates space, the real abstraction of space and not just spatial relations which—in the form of image schemas—are a foundation of reason. Expressed differently, we need the sense of the reality of an outside world as distinct and distant from ourselves, a reality whose structure matters and needs and wants to be controlled and understood. It is simply not so that a mythic mind would ever have the need for creating and believing in accounts of the true material structure of the universe as being the result of the existence and the motion of countless little particles in otherwise empty space.

The second problem is scientific. We need to know the foundational mythic concepts of physical science to link microscopic models to the reality perceived by the human mind. It is impossible to create statistical explanations of thermal phenomena without first knowing what temperature means. If we say that temperature is explained in terms of the energy of the motion of little particles, we are fooling ourselves. A statistical mechanical model of a gas, for example, can only deliver relations between mechanical variables and energy. If we wish to state what this has to do with the temperature of the gas, we have to know temperature as an independent concept. There is simply no way we can pull ourselves up by the bootstraps of little particles and believe that through them we understand the world around us.

This paper is not the place to explore the constructive side of particle models of natural structures and phenomena. Beyond alluding to the notion of empty space and our mythic roots as necessary ingredients of such a model of reality I have said nothing about the conceptual foundations of microscopic physics and chemistry. There is no doubt that microscopic models are important in our culture, but this does not mean that we can overlook the questions I have raised and blindly treat little children to little particles without regard of the development of their mind. If and when we want to introduce students to our modern story of the microscopic structure of the world, we have to know what we are doing. Interestingly, astronomy may very well be the best path to the world of atoms and particles as it allows us to develop the notion of space that is so important for our modern perspective.

7. Some Final Remarks

You probably realize that a good part of what I have been talking about in the last few paragraphs goes well beyond primary school education. So let me finish with a word of warning lest we run the danger of wanting to hurry along an education that requires care and time. We should keep in mind that romantic realism, theoretic or formal thinking, and the abstraction of space are late developments, late in history and late in the development of the mind of a child. I do not know exactly how late—this is a question that must yet be answered empirically. Literacy and an intense interest in the variety and extremes of the outside world develop, change, and grow well into adolescence, and probably well beyond. The concept of empty, infinite space—and the meaning of microscopic models of reality—will not arise without a solid experience and knowledge of self. A deep understanding of the reality and meaning of theories follows even later. If romantic realism, theoretic understanding, and the notion of space, are results of the growth of the experience of self, this hesitant course of change and growth will not appear so surprising.

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