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Should Science be Taught in Early Childhood?

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This essay considers the question of why we should teach science to K-2. After initial consideration of two traditional reasons for studying science, six assertions supporting the idea that even small children should be exposed to science are given. These are, in order: (1) Children naturally enjoy observing and thinking about nature. (2) Exposing students to science develops positive attitudes towards science. (3) Early exposure to scientific phenomena leads to better understanding of the scientific concepts studied later in a formal way. (4) The use of scientifically informed language at an early age influences the eventual development of scientific concepts. (5) Children can understand scientific concepts and reason scientifically. (6) Science is an efficient means for developing scientific thinking. Concrete illustrations of some of the ideas discussed in this essay, particularly, how language and prior knowledge may influence the development of scientific concepts, are then provided. The essay concludes by emphasizing that there is a window of opportunity that educators should exploit by presenting science as part of the curriculum in both kindergarten and the first years of primary school.

KEY WORDS: children's scientific thinking; K-2 science education; justifications for early science teaching; windows of opportunity.

INTRODUCTION

Early in his life, the physicist Enrico Fermi resolved "to spend at least one hour a day thinking in a speculative way" (Ulam, 1976, p. 163). Although it may not be advisable for researchers to engage in speculation as such, it is healthy to step back every once in a while—if not 1 h a day—and consider some of those fundamental issues that rigorous and specialized research all too often forces us to put aside. Accordingly, in this essay we shall stop and look at the basic question, Why should children in preschool or in the first years of elementary school be exposed to science? Specifically, based on existing research literature, we shall attempt to formulate a set of explicit justifications for science education in early childhood.

For high school students or young adults, it tends to be easier to find explicit justifications for science education. No doubt, this is because the possibility of a scientific career begins to be imminent for students of this age—and because this is the age when students themselves ask for justifications of all sorts! Gerald Holton, for example, gives these reasons why students nearing or beginning university studies (and not necessarily bound to choose a scientific career) ought to be exposed to science:

> . . . to serve as basic cultural background; to permit career-based opportunities for conceptual or methodological overlap; to make one less gullible and hence able to make more intelligent decisions as a citizen an parent where science is involved; and last but not least, to make one truly sane (for while scientific knowledge is no guarantor of sanity, the absence of knowledge of how the world works and of one's own place in an orderly, noncapricious cosmos is precisely a threat to the sanity of the most sensitive persons) (Holton, 1975, p. 102)

As reasons, these are perfect valid, and we agree with them; however, for the most part, they are grown-up reasons. One might argue, of course, that reasons such as Holton's are the true justifications for studying science, and that young children should

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be exposed to science only to get an early start on the path towards fulfilling those ultimate aims. But this kind of argument only avoids the question: our task is to find reasons that truly fit young children—not grown-up reasons—reasons which will allow educators to feel that in exposing 4-, 5-, 6-, 7-, or 8-year-olds to science they are really doing the right thing. Needless to say, how teachers feel about science is not to be belittled. More than one study in science education refers to elementary school teachers' negative attitudes towards science (Gustafson and Rowell, 1995; McDuffie, 2001; Parker and Spink, 1997; Skamp and Mueller, 2001; Stepans and McCormick, 1985; Tosun, 2000; Yates and Chandler, 2001); such attitudes can only be reinforced, if not caused, by a sense that science teaching in early childhood may at bottom be a merely nugatory exercise.

In pursuing our goal, we shall proceed in this essay as follows. First, we consider two basic justifications of science education, namely, that science is about the real world and that science develops thinking. Although in the end we do not reject these claims, we do show that, by themselves, they are fraught with difficulty and need to be qualified. With these qualifications in mind as well as research pertaining to children's cognitive abilities, inclinations, conceptions and misconceptions, we present in the second part of the essay our own explicit justifications for science educations in early childhood. Finally, we consider some particular learning situations in line with the justifications set out in the second part.

SCIENCE AND TWO BASIC JUSTIFICATIONS FOR SCIENCE EDUCATION

As a term, 'science' is used to describe both a body of knowledge and the activities that give rise to that knowledge (Zimmerman, 2000); whether justified or not, one generally refers to an account of atoms, forces, chemical processes as well as one of observing, measuring, calculating as 'scientific.' Science indeed may be thought of as comprising two types of knowledge: domain-specific knowledge, and domain-general knowledge or domain-general strategies (Zimmerman, 2000). Domain-specific knowledge refers to the knowledge of a variety of concepts in the different domains of science. Domain-general knowledge refers to general skills involved in experimental design and evidence evaluation. Such skills include observing, asking questions, hypothesizing, designing controlled experiments, using appropriate apparatus, measuring, recording data, representing data by means of tables, graphs, diagrams, etc., interpreting data, choosing and applying appropriate statistical tools to analyze data, and formulating theories or models (Keys, 1994; Schauble *et al.*, 1995; Zimmerman, 2000). The division between domain-specific and domain-general knowledge mirrors other analogous and well-known distinctions, for example, that between conceptual and procedural knowledge, especially in its most general formulation as the division between 'knowing that' and 'knowing how to' (e.g., Ryle, 1949).

This division in the use of the word 'science' and the kinds of knowledge it embraces corresponds to the two main justifications science teachers often suggest for why even preschool students should be exposed to science:

(a) Science is about the real world.
(b) Science develops reasoning skills.

The first statement emphasizes, obviously, domain-specific or conceptual knowledge: by understanding scientific concepts in specific domains children might better interpret and understand the world in which they live. The second statement emphasizes domain-general or procedural knowledge: 'doing science,' it claims, contributes to the development of general skills required not only in one specific domain, but also in a wide variety of domains, not necessarily scientific ones.

These two justifications are hardly new; they have accompanied the development of science education tenaciously since the 19th century. Reformers in England, such as Richard Dawes and James Kay-Shuttleworth in the mid-19th century, stressed in their defense of science education the importance of 'useful knowledge' and of 'teaching the science of common things' (see Layton, 1973, esp. chap. 5); students, in other words, should study science because through it they learn about their own world, about the things around them. On the other side of the divide, stood figures such as John Stevens Henslow (better known because of his influence on the young Charles Darwin). Henslow was a botanist and thought of systematic botany as a model subject for science education; he did so, however, not because of its intrinsic interest but because it was, for him, an ideal vehicle for learning observation, exercising memory, strengthening critical thinking, and so on (Layton, 1973, chap. 3). T. H. Huxley, too, belonged to Henslow's camp, and his much-quoted statement that "Science is nothing but trained and organized common sense" (Huxley, 1893, p. 45) summarizes the credo that science should be taught because, in some general way, it help forms powerful ways of thinking.

That science is about the real world and that it develops reasoning both seem even now reasonable enough claims—at least as much so as the division in scientific knowledge from which they are derived. But though teachers continue to use these claims as justifications for teaching science to children, historians and philosophers of science, and scholars in science education as well, have shown them to be problematic and needing qualification. Let us, therefore, take a brief look at the difficulties with these two basic justifications.

Is Science About the Real World?

Driver and Bell (1986) accept that science, in some sense, is about the world; however, they also argue that "it is about a great deal more than that. It is about the ideas, concepts and theories used to interpret the world." Einstein and Infeld have stated this position famously as follows:

> Science is not just a collection of laws, a catalogue of facts it is the creation of the human mind with its freely invented ideas and concepts. Physical theories try to form a picture of reality and to establish its connections with the wide world of sense impressions (Einstein and Infeld, 1938).

Thus, one cannot say, simply, that science is 'about the world' for, as the Einstein-Infeld quotation suggests, one must distinguish between a world of 'sense impressions' and a world of 'ideas and concepts' (Driver and Bell, 1986). And, far from what Popper liked to call the 'Baconian myth' (Popper, 1963), abstracting facts into concepts or theories does not follow from simple observation and experiences in the world. On the contrary, according to Schwab and Brandwein (1966), the conceptions and ideas created by the human mind have much to do with how we observe and experience the world: "It tells us what facts to look for in the research. It tells us what meaning to assign these facts" (p. 12).

Consider the following example (the reader may find another example in Driver and Bell (1986)): A child gently kicks a block on the floor so that the block moves forward a little. The sense impression of this 'real world' experience includes the block and its motion, the floor, and the child that we can see. However, the explanation of the case involves the concepts of force, mass, friction, velocity, and acceleration—but none of these is immediately observable; none belongs to the world of our senses or even able to be abstracted in any direct way from it. Physics concepts like force and mass guide our observations; they tell us what to look for. Thus, only after one comprehends concepts such as velocity, acceleration, and force does one interpret and describe the block's behavior in those terms.

It is not surprising, therefore, that research on science education in the last three decades provides ample of evidence that both students *and teachers* hold misconceptions in variety domains (Newtonian mechanics: Clement, 1982, 1987; McCloskey, 1983; Electricity: Cohen *et al.*, 1983; Geometrical optics: Galili and Hazan, 2000; Guesne, 1985). For example, in the above case with the block, it is well documented in the literature (Halloun and Hestenes, 1985) that most students believe mistakenly that the 'kicking force' still exist and continues to act on the block even after the boy's foot has left it. As to why the block eventually stops, most students will explain that this is because the force acting on it finally 'runs out.' These ideas, of course, are consistent with the quasi-Aristotelian notion held by many students that where there is motion there is a force producing it (Viennot, 1979; McCloskey, 1983). Giving an account of the 'simple' real world occurrence, the kicking of the block, requires the understanding of abstract concepts and principles. Moreover, even those who understand the relevant concepts and principles may find it difficult to apply them in this kind of 'real world' case; understanding scientific concepts is not an easy task even by adults. Indeed, Wolpert, in his book on *The Unnatural Nature of Science* (1992), makes the point that, "Scientific ideas are, with rare exceptions, counter-intuitive: they cannot be acquired by simple inspection of phenomena and are often outside everyday experience . . . doing science requires a conscious awareness of the pitfalls of 'natural' thinking" (Wolpert, 1992, p. xi).

To summarize, it is true that science allows one to see the world, but it does so through its own special concepts. Thus, Driver, Guesne, and Tiberghien say that, "In teaching science we are leading pupils to 'see' phenomena and experimental situations in particular ways; to learn to wear scientist's 'conceptual spectacles'" (Driver *et al.*, 1985, p. 193). But if science is more than what we experience directly with our senses, if it is somehow an 'unnatural' activity, as

Wolpert says, and if understanding scientific concepts and applying them in specific 'real world' situation is difficult even for adults, we need to ask even more urgently, Should young children indeed be exposed to scientific concepts? Perhaps, we should wait until they are more mature intellectually and more able to handle scientific ideas. Moreover, researchers have shown that ideas which take shape in early childhood do not readily disappear with age, but prove to be disconcertingly robust (Black and Harlen, 1993; Gardner, 1999). Should we worry, then, that by exposing children to science before they possess the cognitive ability to cope with science, we might, unwittingly, cause misconceptions to take root, which will be hard to undo later on in school, rather than preventing them?

We shall return later to the problem of children's conceptions and misconceptions and the to the questions above. But for now, let us just keep them in mind and consider the second basic justification for science education, namely, that science education might contribute to the development of scientific reasoning.

Does Science Develop Reasoning Skills?

At the heart of scientific reasoning both within and outside of professional science is the coordination of theory and evidence (Kuhn and Pearsall, 2000). Taken by themselves, knowledge of theory and knowledge of evidence, naturally, are instances of domain-specific knowledge. From the last section, however, it is clear that science is not science where there is no pairing between theory and evidence. But the coordination of theory and evidence involves inquiry skills or domain-general knowledge, and, for this reason, inquiry is considered inherent to science. Science education is thought to contribute to the development of scientific reasoning, accordingly, by engaging students in inquiry situations. This is the view expressed by Chan, Burtis, and Bereiter when they say that in formulating questions, accessing and interpreting evidence, and coordinating it with theories, students are believed to develop the intellectual skills that will enable them to construct new knowledge (Chan *et al.*, 1997).

This same view, which, as we mentioned above, has firm historical roots, is also well documented in educational reports playing a part in setting modern policy for science teaching. Moreover, such reports have emphasized the importance of developing scientific reasoning *in all age groups*. Here are two examples

(1) According to the report of the Superior Committee on Science, Mathematics and Technology Education in Israel ('Tomorrow 98') it is extremely important to establish "patterns of investigative thinking as early as pre-school" (1992, p. 26).
(2) The Science as Inquiry Standards of the National Science Education Standards (NSES) also advocates that "students at all grade levels and in every domain of science, should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments" (NSES, 1996).

Literature on scientific reasoning, however, suggests that there are significant strategic weaknesses which have implications for inquiry activity (Klahr, 2000; Klahr *et al.*, 1993; Kuhn *et al.*, 1988, 1992, 1995; Schauble, 1990, 1996). According to Kuhn *et al.* (2000),

> ...the skills required to engage effectively in typical forms of inquiry learning cannot be assumed to be in place by early adolescence. If students are to investigate, analyze, and accurately represent a multivariable system, they must be able to conceptualize multiple variables additively coacting on an outcome. Our results indicate that many young adolescents find a model of multivariable causality challenging. Correspondingly, the strategies they exhibit for accessing, examining, and interpreting evidence pertinent to such a model are far from optimal" (p. 515).

It seems that there is a gap between the belief that science education based on inquiry will promote scientific reasoning and the reality that the cognitive skills necessary to engage in inquiry may not be adequately possessed by students. If even young adolescents, not to mention adults, lack these cognitive skills, surely we cannot expect them in kindergarten and first year elementary school students. But if this is the case, can we expect that young children to benefit from science education based on inquiry?

And can we expect young children, then, to develop the kind scientific reasoning that is supposed to arise from inquiry?

Considering the tremendous amount of money, manpower and time required to develop science curricula and prepare teachers to teach them, questions such as these (which taken together constitute the proposal counter to ours, namely, that science *not* be taught to young children) should not be taken lightly. Now this essay does not presume to give conclusive answers to the difficulties raised in the last two sections. Even so, we do believe it is vitally important to keep such difficulties in back of one's mind so that justifications for science education—including those which we shall presently describe—be adopted soberly and with a degree of caution. That said, we think justifications *can* be given for exposing young children to science that at least make taking up the enterprise more reasonable than rejecting it. To this, then, we now turn.

SIX REASONS FOR EXPOSING YOUNG CHILDREN TO SCIENCE

In this section, we consider six reasons as to why even small children should be exposed to science. These reasons are as follows:

(1) Children naturally enjoy observing and thinking about nature.
(2) Exposing students to science develops positive attitudes towards science.
(3) Early exposure to scientific phenomena leads to better understanding of the scientific concepts studied later in a formal way.
(4) The use of scientifically informed language at an early age influences the eventual development of scientific concepts.
(5) Children can understand scientific concepts and reason scientifically.
(6) Science is an efficient means for developing scientific thinking.

Before we describe each of these in detail, two remarks must be made. First, these six reasons are not completely independent of one another. For example, the third, fourth, fifth and sixth reasons are clearly interrelated. Second, as we stated in the introduction, we are not opposed to the two basic justifications for science education discussed in the last section even though we recognize the difficulties related to them. Thus, our fifth and sixth reasons are completely in line with the general claim "Science develops reasoning skills," and our third and forth reasons with the claim, "Science is about the real world." However, the way our justifications are formulated avoids, to a great degree, the problems in the traditional justifications, as we shall see, and, certainly, gives the teacher reasons for science education relevant specifically to young children.

Children Naturally Enjoy Observing and Thinking about Nature

Aristotle began his work the *Metaphysics* by saying, "All men by nature desire to know. An indication of this is the delight we take in our senses . . ." (*Metaph.* 980a, Trans. R. D. Ross). Aristotle does not use the words 'by nature' (*kata physin*) lightly; for him, the desire to know, even when misguided, is very much at the heart of what it means to be a human being. And he knows that the expression of this natural desire is found not just in the learned discussions of university researchers, but also, as he says, in the mere "delight we take in our senses." This desire to know is not limited to adults. "From birth onward, humans, in their healthiest states, are active, inquisitive, curious, and playful creatures, displaying a ubiquitous readiness to learn and explore, and they do not require extraneous incentives to do so" (Ryan and Deci, 2000, p. 56). In other words, from childhood onwards, humans have intrinsic motivation to know–where by *intrinsic motivation* we mean, following Ryan and Deci (2000), the doing of an activity for its inherent satisfactions rather than for some separable consequence. Indeed, research on children's motivation to learn and their under-achievement reveals that young children are full of curiosity and a passion for learning (Raffini, 1993). When we recognize this we recognize that children's enjoyment of nature—their running after butterflies, pressing flowers, collecting shells at the beach, picking up pretty stones—is also an expression of this basic desire and intrinsic motivation to know. Conversely, we see that children's knowing and learning about nature, indeed our own knowing and learning too, is a kind of openness to and engagement with nature.

Is the children's involvement with nature, however, in any way intellectual, that is, can it be related to science? Are not children just playing? Yes, they are, but as Vygotsky, among others, has made clear to us, playing is, in fact, very serious business; play is, for Vygotsky, a central locus for the development of relationships between objects, meanings, and imagination (e.g., Vygotsky, 1933/1978). The pleasure children take in nature, in playing, in collecting, in observing, make them, in this way, temperamentally ready not only for the things of science but also for first steps towards the ideas of science.

But what makes young children particularly ready for science is their sense of wonder and intrinsic motivation, and, for the educator, this is one of the most important arguments for not neglecting science. Educators must work thoughtfully to preserve that sense of wonder, which is so much directed towards the natural world and natural phenomena. In a beautiful essay entitled *The Sense of Wonder*—which, though nonacademic, really should be required reading for all future science educators!—Rachel Carson makes the case as follows:

> A child's world is fresh and new and beautiful, full of wonder and excitement. It is our misfortune that for most of us that clear-eyed vision, that true instinct for what is beautiful and awe-inspiring, is dimmed and even lost before we reach adulthood. If I had influence with the good fairy who is supposed to preside over the christening of all children I should ask that her gift to each child in the world be a sense of wonder so indestructible that it would last throughout life, as an unfailing antidote against the boredom and disenchantments of later years, the sterile preoccupation with things that are artificial, the alienation from the sources of our strength.
>
> If a child is to keep alive his inborn sense of wonder without any such gift from the fairies, he needs the companionship of at least one adult who can share it, rediscovering with him the joy, excitement and mystery of the world we live in (Carson, 1984, pp. 42–45).

So, the first reason why young children should be exposed to science is that, on the one hand, they are already looking at the things with which science is concerned and already in the way the *best* scientists do, i.e., with a sense of wonder, but, on the other hand, children are in danger of losing their interest and their sense of wonder if we fail to tend to them and nourish them in this regard.

We said that children are already predisposed to learning about the things of science. It is worthwhile to look also at the other direction, i.e., that the world offers them sufficient material to feed their interest. Not only the natural world but also the world constructed by human beings with the help of science imposes itself upon children. Most parents know, sometimes to their chagrin, that, say, a toy telephone will not hold a child's attention the way a real telephone will. Children are easily absorbed by turning a switch and watching a light go on and off. Bicycle wheels, radios, power tools, lenses and prisms, are all objects of fascination and all objects which apply and reflect scientific understanding.

As we discussed earlier, however, the way science ultimately allows us to see the world is by providing us with concepts with which we can frame its phenomena—and it was because these concepts are not always simple or obvious that we questioned wisdom of teaching science to young children. When we consider the remaining justifications we shall reexamine the ability of science education to introduce scientific concepts to young children, but before that, it is important to say that even before concepts come fully into play there is room for *mere looking*, for mere paying attention to phenomena in the world. Such mere looking too is essential to science; indeed, Cesere Cremonini and Giulio Libri's *refusal* to look through Galileo's telescope in 1611 (Drake, 1978, pp. 162–165) still epitomizes an antiscientific spirit.

The world possesses many fascinations, and children, as we said, are taken with them when they see them; often though they need to be turned in the right direction. This is where science education is important in children's early years. By pointing and asking questions, with no further explanation, teachers can help children find an abundance of objects and phenomena that will latter give content to important scientific concepts (a process about which we shall have more to say below). A teacher often does greater service by simply pointing at the heart-shaped curve of light reflected in a cup of milk than by speaking about the concept of a caustic, or by showing how a comb will deflect a stream a water after the comb has been run through one's hair than by speaking about static electricity, or by asking a child why the merry-go-round keeps turning after it has been pushed than by trying to explain the concept of inertia.

Of course, mere looking requires what one might call 'disciplined openness'—the ability to resist premature explanations. So while the richness of interesting phenomena in the everyday world is a reason to expose young children to science, it remains a challenge for teachers (and for science education to help them) to separate the exposure to phenomena from the interpretation of it. The failure to make that separation in teachers' own minds, moreover, is one reason they might hesitate to expose very young children to science, fearing ineluctable misconceptions. But although the danger of misconceptions is real, as we have said and will emphasize again, well designed science education can help students look while maintaining the openness needed to crystallize the scientific concepts which will ultimately allow them a different, more refined, way of looking at the world.

Exposing Students to Science Develops Positive Attitudes Towards Science

Although children have a predisposition to explore the world around them, exposing them to science activities might enhance their motivation and further their natural interest. In addition, we claim that exposing children to science might also inculcate positive attitudes towards science. The term a*ttitudes* has a variety of meanings. However, according to Miller *et al.* (1961), there are several points of consensus that: (1) attitudes are feelings, either for something or against it; that they involve a continuum of acceptance (accept–reject, favorable–unfavorable, positive–negative); (2) that they are held by individuals; (3) that they may be held in common by different individuals; (4) that they are held in varying degrees (there is neither black nor white, only shades of grey between extremes); and (5) that they influence action. For the educator, what is most important is that attitudes influence motivation and interest (Miller *et al.*, 1961). Bruce *et al.* (1997), summarizing the literature, argue, moreover, that positive attitudes toward any school subject are related to achievement, may enhance cognitive development directly, and will encourage lifelong learning of the subject in question, both formally and informally. Attitudes towards science classes also have been found to be the best predictors of students' later intentions to enroll in science classes (Crawley and Black, 1992).

It is clear that development of attitudes towards science begins early (Bruce *et al.*, 1997). As early as kindergarten children's attitudes towards science and their participation in it were strongly defined. If attitudes are formed already at early stages of life, and if they indeed have significant influence on the child's future development, educators ought to build environments in which students will enjoy science and have positive experiences connected with it.

Early Exposure to Scientific Phenomena Leads to Better Understanding of the Scientific Concepts Studied Later in a Formal Way

Through experience in everyday life, even when very young, we acquire knowledge about things. We do not only acquire experience and store it but rather organize it. We identify categories of things, like dogs, in part to avoid having to remember every single dog we have seen. Thus, our knowledge is organized in such a way that it decrease the amount of information we must learn, perceive, remember, and recognize, for this reason, Collins and Quillian (1969) aptly called their own suggestion for an organizational principle, 'cognitive economy.' This economy facilitates the reuse of previous knowledge structures when possible. This means that general concepts, for example the concept 'cat,' in this view, are treated in terms of efficiently organized information. According to Heit (1997) perhaps the most dramatic example of concept learning is the performance of young children, who can learn up to 15,000 new words for things by the age of six (Carey, 1978). Admittedly, knowing the word 'cat,' say, and knowing the concept *cat* are two different achievements, they are, nevertheless, closely related (Clark, 1983). Concepts consist of verbal as well as nonverbal knowledge representations, including information in the various sensory modalities (Paivio, 1986; Kosslyn, 1994). The concept 'cat,' then, not only consists of verbal information such as 'a cat is an animal with four legs, fur, *etc.*,' but also, *visual* information—an image of the cat; *haptic* information—we may remember the feeling of a touch of a cat; *aural* information—every one can repeat the *miao* sound of the cat; *olfactory* information—we might even bring in the smell of a cat (especially those who have cats).

Learning a new category is greatly influenced by and dependent on one's previous knowledge and what one knows about other related categories (Heit, 1997). Thus Ausubel could write:

> If I had to reduce all of the educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly. (Ausubel, 1968, Epigraph)

More specifically, Heit (1994) points out that the learning of new categories involves the integration of prior knowledge with new observations. According to him, the initial representation of a new category is based on prior knowledge and is updated gradually as new observations are made. This too, we might add, is not inconsistent with *constructivist* perspectives, where one of the main tenets is that learning, construction of novel understandings, and making sense of new experiences are built on prior existing ideas that learners may hold (Driver and Bell, 1986).

From what we have said it stands to reason that early exposure to science-related activities with rich verbal and nonverbal information will lead to the formation of deep reservoirs of material which, little by little, may become organized into rich concepts. Negative, and sad, evidence for this, of course, is the poverty of scientific concepts among students whose childhood was spent in poor socio-economic environments. Indeed, according to Lee (1992) cultural funds of knowledge, brought from students' home lives, provide a basis for making sense of what happens at school and constitute the building blocks on which new knowledge can grow. Students from upper-middle- and upper-class families possess a cultural advantage for achieving school-related success that lower-class students do not (Bourdieu, 1992; Sahlins, 1976; Wills, 1977).

But since the child's world is full of things related to science anyway, as we said above, it would seem that no special effort has to be made to ensure that children encounter scientific phenomena and that early exposure to scientific phenomena, therefore, need not be an issue for science education. We would argue, however, that *how* children are brought to such phenomena must be pursued with care; we must make sure that while the exposure to scientific phenomena be rich, it should not be capricious. This is because children will begin the process of organizing their experiences into concepts whether we like it or not, and everything they are exposed to will come into play, one way or another. It is not surprising, then, that research has found that novices' concepts are often different from the accepted scientific concepts. Furthermore, these preconceived notions may be inadequate for explaining observable scientific phenomena (Bonder, 1986; Cho *et al.*, 1985; Sanger and Greenbowe, 1997) and may produce systematic patterns of errors (Smith *et al.*, 1993). Such conceptions of students have been labeled by a wide variety of terms in the literature, including misconceptions, preconceptions (Clement, 1982), alternative conceptions (Hewson and Hewson, 1984), and naïve beliefs (McCloskey *et al.*, 1980). According to Smith *et al.* (1993), these terms all indicate fundamental differences between novices and experts. But such terms also indicate the fact we have been emphasizing here, namely, the simple fact that whether they are misconceiving or preconceiving, children are ever engaged in forming ideas about the world.

This last fact, which, in a way, is the foundation of the constructionist vision of learning, suggests that processes of learning, construction of novel understandings, making sense of new experiences are all ongoing and all influenced by and built on learners' prior existing ideas. Whatever misconceptions children have acquired, then, will also guide their subsequent reasoning. It has been found, moreover, that those misconceptions may be deep-seated and resistant to change (McCloskey, 1983). Designing learning environments in which young children are exposed in a paced and controlled way to scientific phenomena, may help children organize their experiences so as to be better prepared to understand the scientific concepts that they will learn more formally in the future.

The Use of Scientifically Informed Language at an Early Age Influences the Eventual Development of Scientific Concepts

In the last section—and, to some extent, also the first two sections as well—we stressed paced and thoughtful exposure to scientific phenomena as a way to guide the eventual formation of scientific concepts; in other words, the reasons we gave for exposing young children to science always placed scientific concepts in the future. But if there is any truth in what we said at the beginning of this paper, exposing children to science cannot be so easily divorced from exposing children directly to scientific concepts. What this means is that while 'mere looking,' as we stressed above, is essential to science, making a case for exposing young children to science requires also justifying talking science, that is, using scientific concepts. The question here is, in a way, the opposite of that in the last section: here we need to ask not how experience will help develop scientific concepts but how introducing scientific concepts may influence how children see the world. However, one should also be aware that language and prior knowledge are strongly related to each other. Language, as we shell show, contributes to the formation of the prior knowledge. In this sense, this section is continues of the previous one.

The question of how introducing scientific concepts may influence how children see the world, in more general terms, is the question of how language and intellectual development interact. As for this, there have been, as Boyle (1971) points out, three traditional schools of thought: the Russian school, dominated by Vygotsky, saw language as the principal mediator of all higher mental functions (see Vygotsky, 1934/1986) and, therefore, as virtually a *sine qua non* of mental growth; the Genevan school under Piaget saw intellectual development as a more or less biological process which is neither initiated nor sustained by language but which is certainly reflected in the child's use of language; the Harvard school, taking a sort of middle road, regarded language as a valuable tool employed by individuals in shaping their experience.

Partly because of the arguments adduced already in the previous sections, our general theoretical outlook leans towards the moderate position of the Harvard school. To begin with, it is clear that experience with science, not necessarily verbal, can be extended and can enrich other experiences, causing, say, children to look at phenomena which they might otherwise have ignored; but it is also clear that language facilitates this process. Consider, for example, a child who played with pulleys in his kindergarten. Now imagine that the child went with his parents on a skiing trip and, there, rode on a ski lift. Being exposed in the kindergarten to pulleys increases the chances that the child will notice that there are pulleys in the lift system. She might now talk to her parents about the pulleys and might even tell to the kindergarten teacher that she saw pulleys in a ski lift. Being exposed to pulleys in the kindergarten prepared the child to notice the pulleys which otherwise she probably would have ignored, but having also the language to speak about them allowed her kindergarten experience to enter into her after-school experience and then her after-school experience back again in her kindergarten.

The way experience and our understanding of experience can influence language has been observed by Galili and Hazan (2000) in connection to optical phenomena. They argue that language, historically, was developed under the influence of visual perception and well before our present understanding of vision was reached. As a result, many linguistic constructions do not conform to present-day scientific knowledge and may lead to student misconceptions. Phrases in our daily language such as "throw a glance" or "give a look," in the authors' view, are probably related to the ancient, and incorrect, Empedoclean idea that vision involves the emission rather than reception of light by the eyes. In a similar manner, Eshach (2003) has shown that the way we talk about shadows in our daily lives may also reveal a strong association between language and ideas regarding shadows; according to him, we talk about shadow as an existing entity, e.g., "look at my frightening shadow," "my shadow follows me," and so on. Such phrases may lead students, and adults as well, to attribute the properties of material substances to shadows, rather than to understand them as the product merely of the absence of light. The influence of language might also explain why many students think that "when two shadows overlap, one may diffuse the other"; similarly, the use of the word 'ray' rather than, say, 'flux,' may be related to students' misconception that there is nothing between the light rays, so that as the distance increases, the area of "nothing" increases and, as a result, a bigger diffused shadow will be created (Eshach, 2003). So, just as a particular understanding of optical phenomena may influence language, language can also shape the way one thinks about optical phenomena.

A further example of how language can affect experience comes from investigations concerning students' understanding of sound (Eshach and Schwartz, 2004). All the students in the authors' research used the phrase 'sound waves' when explaining sound. The authors argued that it is apparent that most students' mental image of sound is similar to that of water waves. They believe that sound is a type of matter that travels through water in a sine-wave-like pattern moving up and down. Thus, during the interviews most of the students used up, down, and forward hand movements to describe how sound travels. In day-to-day language, the term 'wave' is commonly used in reference to sound, i.e., 'sound waves.' When describing voice as 'waves,' physicists actually mean, of course, that the change in the medium pressure (either solid, liquid or gas) may be expressed as a wave function. The term wave has nothing to do with the shape of the 'voice trajectory path.' The apparently correct expression 'sound waves' used in day-to-day language is interpreted literally, rather than conceptually. As a result, people mistakenly associate sound waves with water waves.

How language influences science-related thinking is strikingly apparent in multi-cultural study such as that carried out by Hatano *et al.* (1993) concerning children's ideas of the concept *living*. In English, the one term *living* is sufficient to distinguish living and nonliving things. In Hebrew, however, there are three basic terms relating to living and nonliving things—plants, dead objects, and animals. Comparing American and Israeli students, Hatano *et al.* (1993) provided kindergarten, grade 2, and grade 4 students with lists of items including humans, animals, plants and various other inanimate objects. The students were asked to categorize the items in the list as *living* or *nonliving*. They were also asked questions relating to these categories such as, Can this thing die? or Can this thing grow? The authors found that, for example, only 60% of the Israeli students categorized plants as 'living things' whereas almost 100% of the American and the Japanese students did so. The authors argued that these differences stem from the differences between the Hebrew and English languages, noting that in Hebrew there is a strong association between the term 'animal' and 'living' which does not exist between 'plant' and 'living' (in Hebrew, animals and only animals are called, literally, 'life-owners'). Moreover, while in English one verb, 'to grow,' suffices for both plants and animals (including human beings), in Hebrew, there is one verb for animals and a separate verb for plants. Similarly, while in English one says, equally, that a plant, an animal, or a human being 'dies,' in Hebrew, there are distinct terms for plants and animals.

These examples not only make clear the potency of language to shape experience but also how conflicts can occur between everyday language and scientific language. It is part of scientists' education to get over these conflicts, but should it be a part of children's education as well? Should we perhaps avoid scientific language with children, and encourage only everyday language? Would this not still leave room for language's facilitating role in extending and enriching children's experience with scientific phenomena, as in the example of the pulleys and ski-lift? Would it not be better to keep scientific concepts for the future? Our view is that to avoid the tension existing between everyday language and scientific language and, by that, to avoid possible misunderstandings and misconceptions is to misunderstand how that tension is essential in the learning of scientific concepts. In this we tend to agree with Vygotsky when he writes that "...to introduce a new concept means just to start the process of its appropriation. Deliberate introduction of new concepts does not preclude spontaneous development, but rather charts the new paths for it" (Vygotsky, 1934/1986, p. 152). For Vygotsky, the introduction of scientific concepts sets off a process in which the scientific concept reaches downward towards the child's everyday or spontaneous concepts while the child's everyday understanding reaches upwards towards the scientific concept (Vygotsky, 1934/1986, pp. 194–195; it is in this context, incidentally, that Vygotsky introduces his famous 'zone of proximal development'); the tension created is only a sign that this process is underway.

Another advantage of using scientific language as early as childhood lies in the idea that conversations might also influence how one thinks. According to Sfard (2000) "...what happens in a conversation along the interpersonal channel is indicative of what might be taking place in the 'individual heads' as well." In other words, the mechanism of thinking, according to the author, is "...somehow subordinate to that of communication." Thus Sfard can say, "Both thinking and conversation processes are *dialogical* in character: Thinking, like conversation between two people, involves turn-taking, asking questions and giving answers, and building each new utterance—whether audible or silent, whether in words or in other symbols—on previous ones in such a manner that all are interconnected in an essential way." This at least suggests that if we expose children to 'science talk' it will help them to establish pattern of 'scientific conversations' which might assist in developing patterns of what we call 'scientific thinking.' As Brown and Campione (1994) put it:

> It is essential that a community of discourse be established early on in which constructive discussion, questioning and criticism are the mode rather than the expectation. Speech activities involving increasingly scientific methods of thinking, such as conjecture, speculation, evidence and proof become part of the common voice of the community (Brown and Campione, 1994, p. 229).

In order to create such a community of discourse in the classroom, teachers may first simply be aware of the influence of language on the reception, internalization, and comprehension of scientific concepts and prepare themselves accordingly. Subsequently, they may actively include phrases in their discussions with the students that encourage discourse—simple phrases such as, "How do we know?" "Let's hypothesize," "What do you think may happen if...?" "How did we get to that conclusion?" "Let's check," "How can we check?" (More specific and fuller examples of how appropriate language may be used to promote scientific understanding in the section below, "SOME LEARNING SITUATIONS—LANGUAGE AND PRIOR KNOWLEDGE").

Children can Understand Scientific Concepts and Reason Scientifically

Early in the article, we discussed how concepts or theories, which are not the result of mere direct experience of the world with our senses, are often hard to understand, even by adults. Does this still stand as an objection to what we have just be arguing? Is there any evidence that children are indeed able to deal with scientific concepts, that is, that they are sufficiently mature intellectually to comprehend scientific concepts? This question is still crucial. We can agree that: (a) children naturally enjoy observing and thinking about nature; (b) exposing children to science develops positive attitudes towards science; (c) early exposure to scientific phenomena leads to better understanding of the scientific concepts studied later in a formal way; and (d) the use of scientifically informed language at an early age influences the eventual development of scientific concepts. But, if children are not mature enough to think scientifically, if they are not mature enough to understand scientific concepts, which are often subtle and sometimes complicated, can we truly gain much from exposing them to science?

True, scientific concepts may be hard to grasp even by adults; however, this does not mean that children *cannot* think abstractly about scientific concepts. On the contrary, literature shows that children are able to think about even complex concepts.

Metz (1995), for instance, critiques the assumption that children at the concrete operational level are ‘concrete thinkers,’ whose logical thought is linked to manipulation of concrete objects. This assumption is supposedly derived from Piaget’s work, but Metz argues that a close look at Piaget’s writings themselves give little evidence that this is what Piaget truly thought. She claims that Piaget did indeed believe that school children’s thinking is directed towards some concrete referent, but not that the product of their thinking is concrete. According to Metz, Piaget writings reveals numerous examples of abstract constructs which were formulated, at least on an intuitive level, by elementary school children; these include speed (Piaget, 1946), time (Piaget, 1927/1969), necessity (Piaget, 1983/1987), number (Piaget *et al.*, 1941/1952), and chance (Piaget and Inhelder, 1951/1975). One specific example provided by Metz (1995) is the case of cardinal numbers. Piaget *et al.* (1941/1952), she says, believed that children develop an understanding of cardinal number, an idea that clearly transcends the concrete, around 7 or 8 years of age. Even earlier, between 6 and 8 years of age, Piaget claimed that children come to construct the idea of chance, in the sense of the “nondeductible character of isolated and fortuitous transformations” (Piaget and Inhelder, 1941/1975, p. 214).

Another objection to what we have been arguing in the previous sections may arise from our earlier discussion of science education based on inquiry, namely, that the gap between the belief that science education, based on inquiry, will promote scientific reasoning, and reality according which even young adolescents may not possess the cognitive skills necessary to engage in inquiry (Kuhn’s *et al.*, 2000). Kuhn’s *et al.* (2000) conclusion, in this regard, concurs with early cognitive development research (Inhelder and Piaget, 1958; Kuhn *et al.*, 1988; Dunbar and Klahr, 1989; Schauble, 1990). These researchers suggested that before the age of about 11 to 12 years children have very little insight into how hypotheses are supported, or contradicted by evidence, and that even at this age, and into adulthood, understanding is quite shaky (Ruffman *et al.*, 1993).

Other research, however, shows that even younger children show the ability to think scientifically. For instance, Gelman and Markman (1986) showed that 4-year-old subjects could appropriately select surface information or deeper natural-kind membership information to form inductions, depending on the question asked. Ann Brown’s (1990) study of 1 to 3-year-olds exploring simple mechanisms of physical causality documented that toddlers reasoned from deep structural principles, as opposed to surface features, when they had access to deeper information. Ruffman *et al.* (1993) showed that already by 5 years of age children may distinguish between a conclusive and an inclusive test of a hypothesis.

There are several explanations for the difference of opinion in the research community as to whether or not small children can think scientifically. For instance, Sodian *et al.* (1991), criticizing Kuhn *et al.* (1988) (see for more detailed description of this paper the reader may see example a on the next page), pointed out that: 1) The tasks discussed included contexts in which children had strongly-held beliefs of their own. It is very plausible that revising such beliefs is more difficult than forming theories when no prior beliefs exist or when beliefs are not held with any degree of conviction. 2) The tasks were too complex. Consequently, according to Sodian *et al.* (1991), Kuhn’s *et al.* research tended to underestimate children’s understanding of hypothesis-evidence distinction.

We wish to present another problematic issue concerning these kinds of research. Although cognitive development studies refer to “scientific thinking,” “scientific reasoning,” or “scientific discovery,” and intend the processes by which children explore, propose hypotheses via experimentation, and acquire new knowledge in the form of revised hypotheses, these studies are sometimes carried out in *nonscientific contexts*. Such studies use what Zimmerman (2000) calls *simulated discovery tasks* method. Here are three examples demonstrating this point:

Example a: In a study by Kuhn *et al.* (1988) described in their book *The Development of Scientific Thinking Skills*, children were told that the type of cake eaten—either chocolate or carrot—affected whether or not persons caught colds. Children were then given access to evidence—i.e., they were shown who ate which cake and who went on to catch a cold. They were then asked to explain how the evidence showed the relevance of particular variables, to say which variables were casual, and to conclude which hypothesis was correct. The authors found that when asked to assess the evidence children either ignored the evidence and insisted that it was consistent with their prior theories, or they used the evidence to construct a new theory but failed to grasp that this new theory contradicted their previously-held theory.

Example b: In the study, "Reflecting on Scientific Thinking: Children's Understanding of the Hypothesis–Evidence Relation" (Ruffman *et al.*, 1993, Experiment 1), 4-year-old children were introduced to an imaginary character named Sally. Sally was then said to have gone off to a playground where she could no longer see or hear anything happening near the children. The children were then shown drawings of five boys eating either green (or red) food and had several teeth missing, and another group of drawings of five boys eating red (or green) food who possessed a complete set of strong and healthy teeth. For half the children green food was associated with tooth loss and for the other half, red food was associated with tooth loss. All children associated the correct food with teeth loss, showing that they had no difficulty in interpreting the covariance evidence. The experimenter then 'faked' the evidence by rearranging the 10 pieces of food so that it now appeared that opposite food was the source of tooth loss. With this, Sally 'returned' and observed the evidence; the children were asked to say what kind of food she would say causes kids' teeth to fall out. The children were required, thus, not only to form the correct hypotheses themselves, but also to understand how the evidence might lead Sally to form a different hypothesis. The authors found that 5-year-old children and even some 4-year-old children understood the hypothesis-evidence relation.

Example c: Sodian *et al.* (1991) told children a story about a big mouse or a small mouse living in a house. They were then shown two boxes, each with a piece of cheese inside, and were told that the mouse would eat the cheese if it could. One box had a large opening wide enough for either mouse; the other box had a small opening wide enough only for the small mouse. The children were asked which box they should use to determine whether there is small or big mouse in the house. Children recognized that to determine the size of the mouse it was better to set out the box with the small opening.

In all three examples, children's ability to coordinate evidence with hypotheses was investigated in nonscientific contexts; no scientific concepts were required for the tasks given to the children. While such research contributes tremendously to our understanding of how children connect hypotheses to evidence, it must also be admitted that considering scientific reasoning without engaging in science might provide only an incomplete and inadequate picture of scientific reasoning processes. The tendency to separate scientific reasoning from science may, in fact, be related to the lack of communication between cognitive developmentalists and science educators (Strauss, 1998). Strauss (1998), with whose view we concur, writes, "Developmentalists often avoid studying the growth of children's understanding of science concepts that are taught in school" (p. 358).

To summarize, assuming children are capable to understand complex concepts and are able, even to some extent, to connect theory and evidence, educators ought, in our view, expose children to situations in which those abilities may find fertile ground to grow. In the next section, we shall consider such situations more closely and adduce positive arguments for learning scientific reasoning skills in specifically scientific contexts.

Science is An Efficient Means for Developing Scientific Thinking

On first sight, this statement seems blatantly tautological and, therefore, useless as a reason to justify teaching science. Yet, the issue is more subtle than it appears. For, on the one hand, what goes by the name 'scientific reasoning' or 'scientific thinking' covers more ground than what goes by the name 'science' alone. At the same time, the kind of thinking that real scientists engage in is not necessarily what one likes to call 'scientific.' Let us say a little more about these two points.

First, as we described at the beginning of the paper, science comprises both domain-specific knowledge and domain-general knowledge. In view of this, scientific reasoning, scientific thinking, or scientific discovery includes both conceptual and procedural aspects. The conceptual aspects of scientific thinking are inseparable from scientific content domains; however, the procedural aspects can easily break away from content. It is these procedural aspects that we tend to have in mind when we speak about scientific thinking as analytical or critical thinking or, especially, thinking which connects evidence and theory. In this sense, it can be said that we employ scientific reasoning in our daily lives even when the subject is not science! This is probably the justification for the research, described in the previous section, that investigated so called scientific reasoning in nonscientific contexts.

Having said that, one must be careful about going too far and calling every instance of reasoning, every instance of connecting evidence and theory, as scientific. Consider the following two examples.

(1) Before going to school, John left a new toy, which he had just received for his birthday, on the desk in his room. When he returned from home, the first thing he wanted to do was to play with the toy. But when he went to get it, he discovered it was not where he left it. His parents, as far as he knew, were still at work so, there was no one to ask: he had to solve the mystery himself. How might he proceed? First, he makes some hypotheses: (a) there was thief in the house who stole the toy; (b) one of his parents got back early from work and moved it; (c) his sister, who usually comes home from school before John, took the toy to a friend of hers. Having set out these hypotheses, he can now examine them one by one. Regarding the first, he can check whether any of the windows are open or broken, whether the back door is open or whether there is anything else missing from the house. To test the second hypothesis, he can check whether one of his parents' bags is in the house or some other personal belongings indicating that one of them had arrived before John came home from school. As for the last hypothesis, he can look for signs showing that his sister was already home. For instance, he can check whether or not her room is tidy and arranged as it was in the morning.

(2) A different kind of example in which it might be said that evidence and theory are brought together is this. Based on evidence from their intelligence services, several world governments, the American and British governments chief among them, constructed a theory that Iraq under Sadam Hussein's regime had illicit weapons of mass destruction threatening America, Britain, and other parts of the world. They decided, therefore, to launch a war on Iraq and replace Sadam's regime. The public too is involved in deliberations concerning the war and, to the extent that this is an issue in the presidential election, will have to make a judgment in the end. Based on reports in the media, citizens gather data and form and test different hypotheses. They might weigh new evidence showing the extent Sadam's cruelty, discoveries of mass graves, evidence of horrific torture, and so on, and join this evidence with a theory justifying the removal of nasty leaders by anyone who has the power to do it.

Both of these examples show how the idea of scientific thinking can be pushed too far. Nevertheless, they do bears some marks of genuine scientific reasoning: in the first case, for example, there is the discovery of an anomaly (John's toy not being where he expected it to be), and, in both, hypotheses are formulated and subsequently tested by looking for evidence, evidence is coordinated with the hypotheses, and, perhaps, new hypotheses are formed. The second example diverges from scientific thinking most clearly in that both the governments involved and the voting public are weighing evidence not against a theory of how things are but against what is perceived to be a *desirable* course of action, that is, their reasoning occurs within a value system, not a conceptual system; the fallacy of assuming that this is a *scientific* process was pointed out long ago by Moore (1903), and it is still a fallacy committed by many engaged in social or political issues. The ways in which the first example diverges from scientific thinking are less obvious. The main problem, though, is that while there are hypotheses there is no theory, that is, no overarching view of how things are, no attempt to "…'recognize where on the map' a particular object of study belongs" (Toulmin, 1960, p. 105); hypotheses alone do not make a theory, even a simple minded one. It is important to realize how such cases diverge from scientific thinking because, otherwise, it becomes all too easy to conclude that science is unnecessary for developing scientific reasoning.

In fact, such examples could conceivably be used to develop those elements of scientific reasoning which they do indeed contain: one can learn through them to formulate hypotheses in a sensible way, and one can learn to be critical. But then one would have to be careful to bring out the divergences, which we just described. Learning to recognize such divergences would, of course, not be a bad thing, but it could not be done without some other model examples of scientific thinking. Pursuing scientific thinking in this way, then, would prove to be a cumbersome and unduly complicated affaire. For this reason, our view is that while it is not impossible to use non-science examples to develop scientific thinking, it is more *efficient* to use ones from science.

Take for instance, an investigation of the influence of light on plants; it is rich in domain-general knowledge. First one must identify the relevant variables: the light, the soil type, the amount of water, the temperature, the humidity, and plant species. Then to examine the influence of light, children can design a set of experiments in which all the variables are kept constant except for the light. They can check for changes in the degree or rate of growth, color alterations, light-induced movements (*phototropisms*), and so on. Seeing sets of experiments with only one change is allowed to occur focuses children's attention on the meaning of variables and control variable; they can reflect on the problems which can arise by altering more than one variable; they form hypotheses and suggests ways of testing them; they see how one hypothesis may lead to another. Moreover, they can repeat the experiment to examine the influence of other variables.

Thinking in this context exposes children to 'clean' situations were they can (sometimes even immediately) see the influence of an isolated variable, and, conversely, the complexity of situations where there are many variables and no easy way to control them. Having this kind of experience, then, children are likely to be better prepared to see that even in a 'simple' situation such as that of John's toy, one can not control or isolate the variables. For instance, the open window doesn't necessarily mean that there was a burglar—it might be that the sister and not the burglar opened the window. This is true *a fortiori* with regards to the Iraq example where even the task of identifying the variables is formidable! Thus, by beginning with scientific thinking in scientific contexts—and one ought not forget that the *model* for scientific thinking in any context still comes from science!—children not only learn to be critical and analytical but also learn to see more easily and clearly where other kinds of thinking fails to be 'scientific.'

What it means to be or to fail to be 'scientific' is a question teachers must ask themselves continuously and students, even the very young ones we are speaking about, ought to begin to ask. Popper's ideas, although in other respects outmoded (and we shall have more to say about this in a moment), are still a good starting point for asking what it means to be scientific. Using scientific contexts to develop scientific thinking is also the ideal way to introduce the Popperian view of science. According to Popper (1959) a theory is scientific only if it is falsifiable, that is, if it is such that one indubitable counter-instance refutes the whole theory. Furthermore, while a genuine scientific theory, in Popper's view, can be tested and falsified, it can never be incontrovertibly verified. Neither the most rigorous tests nor the test of time shows a theory to be true; a theory can only receive a high measure of corroboration and may be provisionally retained as the best available theory, until it is finally falsified (if indeed it is ever falsified) or is superseded by a better theory.

An example such as the following does well to illustrate these ideas. Consider the following situation, two objects, one heavier than the other, released from the same height. According to the Aristotelian theory, the objects will reach the ground in an amount of time inversely proportional to their masses. So, for instance, if the mass of one object is twice that of another then it will fall to the ground from the same height in half the time. Now, let's think of the following two experiments:

Experiment 1*:* Release a feather and a stone from the same height. It will be observed that the stone will reach the ground faster. Thus, the experiment apparently proves Aristotle theory that heavier objects, if released from the same height, will reach the ground faster than lighter objects (Fig. 1).

Experiment 2: Repeat Experiment 1, but this time use a sheet of paper instead of a feather (Fig. 2).

Again, the Aristotelian theory holds true. Is there any need to go on? the teacher might ask. Let us perform a third experiment:

Experiment 3: Release two stones, one heavier than the other, from the same height. Let the stones fall onto a hard surface so that one can hear when

Fig. 1. A feather and a stone released from the same height.

they hit the surface. It will be observed that the stones reach the ground at the same moment (and the sound of the two stones hitting the surface will, consequently, be heard simultaneously) (Fig. 3).

Experiment 3 falsifies Aristotle's theory, even though that theory was considered true for over a thousand years, and even though other experiments *were* consistent with what Aristotle thought. Through this example, then, one easily sees how positive experiments are always at best tentative, and, therefore, the scientific theories they are meant to demonstrate must be viewed as tentative as well. This is much more difficult to show in nonscientific contexts. In the example of the boy, for instance, there are too many hypotheses which can all be easily contradicted; the idea of 'falsification' in that kind of nonscientific context becomes highly problematic.

Moving away from this basically Popperian view of science, investigation such as that concerning the influence of light on plants or the falling objects also brings out the second point we made at the start of this section, namely, that the kind of thinking real scientists engage in is not always what one likes to call 'scientific.' For quite some time already the preoccupation of historians and philosophers of science (Kuhn, Polanyi, Feyerabend, etc.) has been the activity of real scientists as creative thinkers who do not necessarily 'follow the rules' of science as opposed to any notion of a fixed 'scientific method.' As Henry Bauer (1994), who refers to the 'myth of the scientific method,' puts it:

> The corpus of science at any stage always includes only what has, up until then, stood the test of time. We see nothing in it of the trial and error, backing and filling, dismantling and rearranging that actually took place in the past, be that centuries ago or just a few years ago. Only when we read the actual accounts written by early studies of nature do we begin to realize how many errors and false starts there were that left no traces in modern scientific texts. Once can give excellent, objective, rational grounds now for the science in the textbooks, but that does not mean that it was actually assembled in an impartial, rational, steady manner (Bauer, 1994, p. 36).

It is only by being involved actively in thinking about something so 'objective' as the influence of light on a plant that one can gain this insight into how science really works. Children will begin to have a hint that, for example, asking whether a plant will

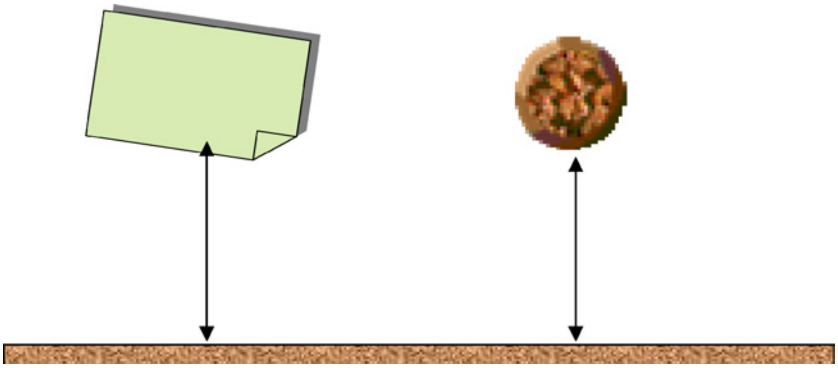

Fig. 2. A sheet of paper and a stone released from the same height.

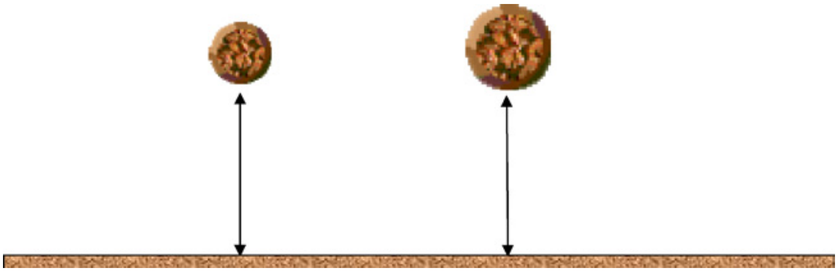

Fig. 3. Two stones released from the same height.

be induced to move by light is not a question dictated by any perfectly determined method; it is the result of their own creativity. And if one believes that this kind of 'philosophical insight' can wait, one ought to consider that in the cartoons they watch and pictures they see young children will be exposed to *other* views of how science works—more often than not a view of science working in a cold, mechanical, inhuman way, according to an inflexible method.

SOME LEARNING SITUATIONS—LANGUAGE AND PRIOR KNOWLEDGE

In this section, we shall provide a selection of learning situations connected with specific scientific concepts. These will provide concrete illustrations of some of the ideas we have been discussing, particularly, how language and prior knowledge may influence the development of scientific concepts.

Heat and Temperature

Many children conceive 'cold' as the equal counterpart to 'hot,' instead of seeing 'cold' and 'hot' in terms of the absence or presence of heat. This misconception is well demonstrated in children's answers to the following question:

"Given two cups, one metal and the other foam, which cup will keep a cold drink cold for longer time? Which cup will keep a hot drink hot for longer time?"

Many students mistakenly believe that a metal cup will keep the drink cold for longer time and the foam cup will keep the hot drink longer. One reason many students provide to their answer is that cold drinks (like coke) are usually kept in metal cans while coffee is usually served in a foam cups to keep it warm. These answers indicate that students separate 'coldness' from 'hotness' as independent qualities, and, it may be surmised, students do so because of their prior everyday experience with hot and cold things.

Simple experiments with even small children may be conducted to show that a foam cup or a thermos keeps *both* hot and cold drinks longer. We believe that such experiments may lead children to understand that the same isolated container can keep hot drinks hot and cold ones cold, though we do not think they will necessarily grasp immediately the precise scientific ideas involved. On the other hand, as we have been claiming throughout, these experiences are likely to make children better prepared to grasp the scientific ideas later.

Optics

Many students believe that shadows are material entities. Feher and Rice (1988) found that nearly 50% of their research participants believed that shadows exist in the darkness, so that a dog, for example, would still have a shadow when it walked into the full shadow of a house. Some participants thought that light was necessary only to illuminate the shadow (as if it were just another object), whereas others believed that light actually caused the shadow's visibility (e.g., by heating it up). Galili and Hazan (2000) found that 9th-grade students (pre-instruction students), 10th-grade students (post-instruction students), and college students (teachers college) regarded shadows as things which can be manipulated as independent objects and can be added or subtracted. They also understood shadows to be things which remain randomly oriented in space, regardless of any light source, that the shadow of the object represents its shape much as its mirror image does, and that light merely "makes [a shadow] visible." In fact, shadows are reified (as in Feher and Rice, 1988) like images in mirrors and lenses. Langley *et al.* (1997) found that most 10th-grade students, before formal instruction, drew light rays that rarely extended as far as the shadow. The authors argued that this indicated that students failed to understand the relationship between light propagation and shadow formation.

It is likely that children will more easily come to understand that a shadow is not an entity itself, if teachers, *already in preschool*, associate shadows with the absence of light rather than the presence of some definite thing. It might help to provide explanations such as this: "You see all around the area of shadow there is light. In the shadow area there is no light (or less light in the case of several light sources)." But since, as we mentioned above, these ideas about shadows may derive from the language used to describe them (Eshach, 2003), teachers can take advantage of language in playful way to challenge children's ideas: besides phrases such as "a shadow follows me" they can say, for example, "a spot of 'no-light' follows me."

Archimedes Law of Buoyancy

The usual answer as to why certain objects float is that they are lighter than the water. Most of students do not grasp that it is the relationship between the relative densities of the object and the water that determines whether or not the object will float, and not their relative weights.

Density is considered a difficult concept for children. Yet, teachers can demonstrate the idea of density even for kindergarten children in ways such as this. First, the teacher fills a container with water and asks what happens if one drops a small stone in the water. Children will generally say that the stone will sink because it is heavier than water. The stone does sink, but is it really heavier than the water? To check, the teacher places the stone on one side of the balance scale and the water, removed from the container and transferred to a plastic bag, on the other. Seeing that the water is heavier than the stone, the students must face the fact that the stone sinks even though it is lighter than the water. From here, the teacher places the stone inside an balloon without inflating it, ties it so that no water can get inside, and asks what will happen to the stone with the balloon if we put them inside the water. The balloon with the stone will sink. However, if we inflate the balloon while the stone is inside, stone-balloon combination will float. The experiment is effective because the weight variable is kept, more or less, constant (in fact, of course, the weight *increases* slightly!) while the volume changes dramatically. Exposing children to the possibility that not only the weight of an object, but also its volume, may determine whether or not an object sinks or floats, paves the way, we believe, to the concept of density and will make it easier to grasp when introduced formally in student's later studies.

Newton Third Law

Consider the following question: Two children, Sharon and Ruth, sit in identical wheeled office chairs facing each other. Sharon places her bare feet on student Ruth's knees, as shown below. Sharon then suddenly pushes outward with her feet. The following three situations should be presented (possibly by using different pairs of children) each at a time: (a) Sharon is bigger than Ruth; (b) Sharon is smaller than Ruth; and (c) Sharon and Ruth are the same size. Who moves when Sharon pushes outwards with her feet, Sharon or Ruth? Explain the answer. Obviously, by the third Newton's law, both will move (though with accelerations depending inversely on their masses) since the force Sharon's feet exerts on Ruth equals the force Ruth's knees exert on Sharon. Yet, many young students believe that whoever is bigger must exert a greater force, that is, the bigger person is somehow the 'more forceful' or 'more active' person. According to Hestenes *et al.* (1992), this belief stems from the way people interpret the idea of 'interaction.' They often use the 'conflict metaphor' according which the 'victory belongs to the stronger.' Thus the more active, heavier, or bigger 'wins' in the 'struggle;' they 'overcome' their 'opponent' with a greater force.

Sharon and Ruth, by being the active agents, as it were, in the experiment described above, have a good chance of realizing that in an interaction between objects not only the stronger exerts a force but that there is a force acting on both objects. It is not our intention, of course, to teach Newton's Third Law to kindergarten children. However, with the right teacher's help, we believe that such experiments where children actually feel the forces at work can help to make the Third Law, which is notoriously difficult to grasp, seem natural and intuitive when it is studied later on.

SUMMARY AND CONCLUDING DISCUSSION

In this essay, we stepped back and considered the question, Why should children in preschool or in the first years of elementary school be exposed to science? Let us review the main points of the essay.

We began by looking at the two basic justifications adduced most often by educators for why even preschool students should be exposed to science, namely, that science is about the real world, and that science develops reasoning skills. Though we did not reject these justifications, we tried to bring out the problematic aspects of them that make it difficult to accept them *tout court*.

Regarding the claim that *science is about the real world*, we showed that science is not about the world in a *direct* way; it, in a sense, is about a great deal more than the world. For one, by abstracting facts into concepts or theories, scientific insights do not follow from simple observation and experiences in the world. Nor are scientific concepts always evident in the way ordinary appearances are—a fact reflected in the difficulty even adults have in grasping scientific concepts. On the other hand, we see the world with the help of conceptions and ideas created by the human mind; they are like glasses that help us be aware of things to which we might otherwise be blind. But this also means that there is a danger of putting on inappropriate glasses that distort our vision. With such glasses, then, children might develop misconceptions that may be difficult to undo later.

As for the claim that *science develops reasoning skills*, we showed that it is not clear that the preconditions for this are always fulfilled. In this connection, we cited literature showing that even young adolescents, not to mention young children, lack the skills required to engage effectively in the many of the forms of inquiry necessary for the first steps in scientific reasoning. Engaging children in tasks requiring investigation might bring them only frustration.

In both cases, one is left with the serious question, Should young children who may not yet be mature to intellectually handle scientific concepts and scientific inquiry indeed be exposed to science? Should we take the risk of introducing science to young children, when, as a result, they might develop misconceptions hard to change later?

With those concerns on the table, we tried to reformulate the arguments for exposing young children to science, so that, in the balance, educators might feel that there are better reasons for teaching science to young children than withholding it from them. The arguments and some of their normative implications, in brief, were as follows:

(1) *Children naturally enjoy observing and thinking about nature*: Whether we introduce children to science or whether we do not, children are doing science. We are born with an intrinsic motivation to explore the world. This means that children will be taking their first steps towards science with or without our help. To prevent missteps, it is wise to intervene and provide learning environments that will conducive to children's developing, in a fruitful way, a scientific outlook and assimilating material for learning scientific concepts later.

(2) *Exposing students to science develops positive attitudes towards science*: Attitudes are formed early in childhood and can have crucial impact on children's choices and successes in learning science. If we wish for our children to develop positive attitudes towards science we must introduce science in a way that will pique their curiosity and spur their enthusiasm.

(3) *Early exposure to scientific phenomena leads to better understanding of the scientific concepts studied later in a formal way*: Prior experience has significant influence on the development of new knowledge. This is a reason for scientific education, with the aid of a sensitive teacher, because how children are brought to such scientific phenomena must be pursued with care; we must assure that while the exposure to scientific phenomena be rich, it should not be capricious.

(4) *The use of scientifically informed language at an early age influences the eventual development of scientific concepts*: Language has a significant influence on concept construction. Sometimes, however, conflicts can arise between everyday language and scientific language. But, following Vygotsky, we argued that these kinds of conflicts and tensions, if accompanied by thoughtful science-educational practice, can be the source of genuine concept development. Approaching the question of language from a different direction, we also argued that the connection between mechanism of thinking and that of communication suggests that exposing children to 'science talk' will help them to

establish pattern of 'scientific conversations' which, in turn, might assist in developing patterns of 'scientific thinking.'

(5) *Children can reason scientifically*: Although some research has shown that children lack the requisite skills to conduct investigations fruitfully, other research has shown that children as young as 4-year-old, can, nevertheless, distinguish between a conclusive and inclusive test for a hypothesis. If children have, thus, the seeds of skills that allow them to connect theory and evidence, it reasonable that exposing them to situations where they can exercise these skills they will further develop them. These situations must be planned in advance so that they fit the children's abilities, and in this science education plays its crucial role.

(6) *Science is an efficient means for developing scientific thinking*: By pursuing scientific thinking in scientific contexts children are more easily exposed to 'clean,' 'objective,' situations were they can see the influence of an isolated variable; children, in this way, not only learn to be critical and analytical, but also learn to see more readily and plainly where other kinds of thinking fails to be 'scientific.'

Ideally, a kindergarten science program would give expression to all six of these themes. But the spirit, at least, of these themes can be found in the preschools of Reggio Emilia, Italy. Referring to a Newsweek article which declared these preschools to be the best in the world, Howard Gardner wrote, "in general I place little stock in such rating, but here I concur" (Gardner, 1999, p. 87). According to Gardner, the Reggio Emilia preschool program is such that groups of children spend several months exploring themes which interest them: sunlight, rainbows, raindrops, shadows, ant colonies, lions' dens, poppy fields, an amusing park for birds built by the youngsters, fax machines. The children approach these things from many angles; they ponder questions and consider phenomena that arise in the course of their explorations; and they end up creating artful objects that picture their interests and their learning: drawings, paintings, cartoons, charts, photographic series, toy models, and replicas. Thus the children of Regio Emilia are allowed to explore the things of nature and science according to their own desire; they are encouraged to ask questions and find ways to synthesize and formulate their thoughts about what they see; they are surrounded by people who believe that these early experiences in science are far from fruitless.

Windows of Opportunities

In the development above, we chose not to emphasize findings from brain science, which some might see as an unforgivable lacuna; nevertheless, one must make choices in such matters! Still, we do not by any means want to imply that brain science ought to be neglected; indeed, it is likely to offer important insights for educational questions in the future. For this reason, we want to close with a few points from those studies that touch on the question whether science should be taught to K-2 children.

In his impressive and insightful book, *The Disciplined Mind*, Howard Gardner (1999) relates how he heard the following pronouncement made by a prominent neuroscientist in a conference:

> "This is the decade of the brain. We are going to know what every region of the brain does and how the various part of the brain work together. And once we have attained that knowledge, we will know exactly how to educate every person" (Gardner, 1999, p. 60).

Gardner, who claims that he generally avoids unpleasant exchanges in conferences, said that this speaker had managed to raise his hackles. Extreme statements beget extreme responses, so, at the conclusion of the talk, Gardner retorted:

> I disagree totally. We could know what every neuron does and we would not be one step closer to knowing how to educate our children (Gardner, 1999, p. 60).

With Gardner, we believe that brain studies will never be able to tell us exactly how we should educate our children. That notwithstanding, it is undeniable that learning has to do with the production of neurons and their interconnections, and, it has been shown, this tremendous productive activity slows down to a close at about the age of ten (Nash, 1997). To ignore these facts (and Gardner certainly does not!) in considering when and how education should begin thus seems to us to be a grave mistake.

Gardner goes on to say:

> Decisions what to teach, how to teach, when to teach, and even how to teach entail value judgments. Such decisions can never be dictated by knowledge

> of the brain. After all, if children learn patterns well when they are young, that constitutes equal reason for teaching them math, music, chess, biology, morality, civility, and hundred other things. Why should foreign language get priority? [the case of language was mentioned by the conference speaker who said that according to brain studies it is better to teach children foreign languages at first grades] You can never go directly from knowledge about brain function to what to do in first grade on Monday morning. And the decision one makes about teaching languages might well differ, and properly so, depending on whether you live in Switzerland, Singapore, Iceland, or Ireland" (Gardner, 1999, p. 61).

We completely concur with Gardner that brain science will never determine what exactly we should teach and how we should do it. Our view that we should teach math, music, chess, biology, morality, civility, and hundred other things, and especially that we should teach those subjects that come under the heading of 'science' is not a deduction from brain science. What we *do* learn from brain research is that, once we have decided that science is important, we may not have all the time in the world to pursue it. In the 1990's, much research was being published showing that leaning in specific domains, where 'learning' is understood as a modification of neural structure, occurs most efficiently within certain 'critical periods' or 'windows of opportunity,' and that these 'windows of opportunity' begin to close at around the fourth grade (Nash, 1997; Shore, 1997). The classic case is foreign languages, which tend to be harder and harder to learn as one gets older. For essential science skills, such as logic and mathematics, the window seems to close quite early (Begley, 1996). It is not that one cannot learn latter in life, but, as Nash (1997) puts it, "... while new synapses continue to form throughout life, and even adults continually refurbish their minds through reading and learning, never again will the brain be able to master new skills so readily or rebound from setbacks so easily" (p. 56).

Of course these findings from brain science, strictly speaking, go against Bruner's famous thesis that "any subject can be taught effectively in some intellectually honest form to any child at *any stage* [emphasis added] of development" (Bruner, 1960, p. 33); however, they do support his intention that subjects, and most of all science, could be taught at a *young* age—indeed, these findings show that science *should* be taught at a young age! It is, therefore, incumbent on the science educator to provide children with environments, materials, and activities, to develop their scientific reasoning while these 'windows of opportunity' are still open. Entering those open windows will prepare children to enter the doors of the society as good citizens possessing the ability to question, to critique, and to learn.

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