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nes to science, many of today's children experience narrow and
l learning opportunities, which, as professor Judah Schwartz writes
to this book, lead ulitmately to a mere caricature of science. One
problem is the wrong—terribly wrong—belief that science is an
subject for early elementary education and certainly for kinder-
tion.

to this prevalent and unfortunate situation, this well-written and
oking book presents the state-of-the-art in science education for
and primary schools. It begins with a thorough theoretical discus-
it is incumbent on the science educator to teach science already at
childhood. It goes on to analyze and synthesize a broad range of
pproaches and themes such as: inquiry-based teaching; learning
entic problems; scaffolding; situated learning; learning through
-verbal knowledge; and informal learning. The book also presents
el strategies to science teaching such as learning science through
ilding, evaluating and redesigning simple artifacts; and Inquiry
erous examples illustrating how the theories presented may be
practice are provided.

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Science Literacy in Primary Schools and Pre-Schools

EDUCATION

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SCIENCE LITERACY IN PRIMARY SCHOOLS AND PRE-SCHOOLS

By

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CONTENTS

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 1990s, 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 later 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 statement 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.

CHAPTER 2

HOW SHOULD SCIENCE BE TAUGHT IN EARLY CHILDHOOD?

Equipped with the six reasons to expose small children to science given in the previous chapter, I now shift from philosophy toward a more pragmatic direction: How should science be taught to children?

I start this chapter with an intriguing story taken from Richard Feynman's charming book *What do you Care What Other People Think* (Feynman, 1989). The story describes how Melville Feynman taught physics to his young child, Richard, during weekend walks through the Catskill Mountain woods. Richard Feynman eventually became a famous, renowned Nobel Laureate in Physics. His father, Melville most likely inadvertently, used rather advanced educational approaches to teach his son. These approaches would undoubtedly have been rare in the schools of those times. I will use this story as a framework to discuss and develop several distinct educational approaches which I believe provide insight into science education in early childhood.

HOW RICHARD'S FATHER TAUGHT HIS SON SCIENCE

> "On weekends, my father would take me for walks in the woods and he'd tell me about interesting things that were going on in the woods . . ."
>
> "One kid says to me, "See that bird? What kind of bird is that?"
>
> I said, "I haven't the slightest idea what kind of bird it is."
>
> He says, "It's a brown-throated thrush. Your father doesn't teach you anything!
>
> But it was the opposite. He had already taught me: "See that bird?" he says. "It's a Spencer's warbler." (I knew he didn't know the real name.) "Well, in Italian, it's a *Chutto Lapittida*. In Portuguese, it's a *Bom da Peida*. In Chinese, it's a *Chung-long-tah*, and in Japanese, it's *Katano Tekeda*. You can know the name of that bird in all the languages of the world, but when you're finished, you will know absolutely nothing whatever about the bird. You will only know about humans in different places and what they call the bird. So let's look at the bird and see what it's *doing* — that's what counts." (I learned very early the difference between knowing the name of something and knowing something.)
>
> He said, "For example, look: the bird pecks at its feathers all the time. See it walking around, pecking at its feathers?"
>
> "Yeah."
>
> He says, "Why do you think birds peck at their feathers?"
>
> I said, "Well, maybe they mess up their feathers when they fly, so they're packing them in order to straighten them out."
>
> "All right," he says. "If that were the case, then they would peck a lot just after they've been flying. Then, after they've been on the ground a while, they wouldn't peck so much any more — you know what I mean?"
>
> "Yeah."
>
> He says, "Let's look and see if they peck more just after they land." (Richard P. Feyman, 1989)

> It wasn't hard to tell: there was not much difference between the birds that had been walking around a bit and those that had just landed. So I said, "I give up. Why does a bird peck at its feathers?"
>
> "Because there are lice bothering it," he says. "The lice eat flakes of protein that come off its feathers."
>
> He continued, "Each louse has some waxy stuff on its legs, and little mites eat that. The mites don't digest it perfectly, so they emit from their rear ends a sugar-like material, in which bacteria grow."
>
> Finally he says, "So you see, everywhere there's a source of food, there's some form of life that finds it."
>
> Now, I knew that it may not have been exactly a louse, that it might not be exactly true that the louse's legs have mites. That story was probably incorrect in *detail*, but what he was telling me was right in *principle*. (Feynman, 1988, pp. 3–4)

The Teaching Avenue of Feynman's Story: A Summary

1. Identifying a problem to be investigated — "Why do birds peck at their feathers?"
2. Making a hypothesis — "Well, maybe they mess up their feathers when they fly, so they're pecking them in order to straighten them out."
3. Making predictions derived from the hypothesis — according to the hypothesis one may expect that birds peck at their feathers more just after landing than after being on the ground for a while.
4. Designing an experiment — identifying a variable that can (1) be measured, and (2) test the prediction. In this case the variable is the "*pecking frequency*."
5. Collecting data — after deciding upon the variable, the measurements are achievable: comparing the differences between the pecking frequencies of birds which had just landed with those which were on the ground for a while.
6. Obtaining results — Richard and his father found that there was no difference in the frequencies.
7. Interpreting the data and arriving at the appropriate conclusions — based on the findings, they reached the conclusion that birds do not peck at their feathers in order to straighten them after flying.
8. Providing the scientific explanation — Richard's father taught him the *principle* that wherever there's a source of food, there's some form of life that finds it.

As an educator, I would say that it might have been better to encourage Richard to provide more hypotheses and to test them as well. However, there is no doubt that while Richard might not have learned the bird's name, he definitely learned something about the nature of science and gained a better sense of what scientific inquiry means. Moreover, he probably understood the *principle* that his father taught him.

The story illustrates quite well the following educational topics: (1) inquiry-based teaching; (2) learning through authentic problems; (3) preference for the *psychological* rather than the *logical* order; (4) scaffolding; and (5) situated learning. After discussing these in detail, I will review further educational topics that should also be kept in mind in teaching K-2 and beyond; These are: (6) learning through projects; and (7) non-verbal knowledge.

From Factual Knowledge to Inquiry Skills

Richard's father taught his son that learning about things should go beyond knowing their names. To make his point clear, Melville, in a sense of good humor, named the bird in different languages. He pointed out that by knowing the name one can only know about humans in different places and what they would call the bird. Richard learned early in life, as he himself writes, "the difference between knowing the name of something and knowing something." I take the term "name" not literally, but rather, as a symbol of factual-knowledge-based teaching. Schwab *et al.* (1966) calls such teaching — *teaching as a dogma*. According to such teaching, the body of a doctrine is conveyed as absolute truths.

According to Perkins (1992) there is ample evidence demonstrating that schools, which predominantly teach by rote, barely succeed in getting students to acquire knowledge, even at the level of mere memorization, let alone achieve a clear and satisfactory understanding of this knowledge. Melville Feynman had good intuition and understood well what has now become clear in many countries: the aim of science teaching should not only be the teaching of accepted content in science (scientific knowledge), but should also provide children with an understanding of the characteristics and procedures of scientific inquiry (Kanari and Millar, 2004). "Inquiry learning is defined as an educational activity in which individually or collectively investigate a set of phenomena — virtual or real — and draw conclusions about it" (Kuhn *et al.*, 2000, pp. 496–497). This importance of inquiry learning is well supported by many educational reports worldwide. For instance, one standard of the National Science Education Standards (NRC, 1996) is the Science as Inquiry Standards, which "highlight the ability to conduct inquiry and develop understanding about scientific inquiry" (p. 105). The need to teach science as inquiry is also important for the reason which Schwab wrote about in 1966,

> the operations required of our elites to meet our present problems are no longer capable of being understood by the public which has had only a dogmatic education. . . . The problems we now face cannot be solved within the bounds of existing doctrines. These problems require new conceptions and fresh doctrines. These fresh doctrines and conceptions can be acquired only by a course of enquiry proceeding by innovation, trial, and failure. . . . Hence the problem we face: to convey to our publics a view of enquiry, especially of scientific enquiry, which is commensurate with its present character. Otherwise, adequate support and assent will not be given to the enquiries our national problems require. (Schwab *et al.*, 1996, pp. 8–9)

In my view, not only can this be done but sowing the seeds of inquiry skills as early as K-2 science education is crucial. In the classic book *The Teaching of Science* (Schwab and Brandwein, 1966), Schwab states that "an enquiring classroom is one in which the questions asked are not designed primarily to discover whether the student knows the answer but to exemplify to the student the sorts of questions he must ask of the materials he studies and how to find the answers" (p. 67). According to Schwab, learning processes that begin with problems may promote children's inquiry skills. Indeed Feynman's story begins with a problem posed to Richard: "Why do you think birds peck at their feathers?" The problem led to learning, but did not, by any means, test Richard's knowledge. The next section elaborates on the learning through problems approach.

LEARNING THROUGH PROBLEMS

"The ability to solve problems is one of the most important manifestations of human thinking" (Holyoak, 1995, p. 267). "A problem is viewed as a gap between where a person is and where he or she wants to be" (Hayes, 1981). In other words, "a problem arises when we have a goal — a state of affairs that we want to achieve — and it is not immediately apparent how the goal can be attained" (Holyoak, 1995, p. 269). In the preface to the National Association for Research in Science Teaching (NARST) monograph, *Towards a Cognitive-Science Perspective for Scientific Problem Solving*, Lavoie (1995), writes that the monograph "was conceived in response to our Nation's need for a population of scientifically literate individuals who can think and solve problems" (p. iv). He also argues that "a focus on problem solving seems to have taken a back seat, not only in our classrooms, but in our respected science education research circles." He advocates that renewing science educators' focus on problem solving is one of the most important subjects of our research and teaching efforts at all levels. In his call one can identify the latent assumption that with appropriate teaching, educators can assist students in developing their problem solving skills. Although there is ample evidence in cognitive psychology literature that problem solving depends heavily on available specific knowledge pursuant to the domain to which the problem belongs, Holyoak (1995), argues that normal people do acquire considerable competence in solving daily problems. He suggests that problem solving depends on general cognitive abilities that can potentially be applied to an extremely wide range of domains. Taking into account the ideas that educators can help students develop problem solving skills and also that these skills can be used to deal with novel situations, I definitely believe that educators should respond to Lavoie's call. I therefore, present not only the view that problem solving skills can and should be developed as early as childhood, but also provide the means with which to apply this view in K-2 science education.

Returning to Feynman's story, Richard was asked to deal with a problem without previously learning about the subject. Although one might agree that developing problem solving skills is important, there remains the issue of what children can gain from dealing with a question when they do not have the necessary background to answer it. Is it dangerous to allow children to become frustrated? To illustrate my concern I will provide an example of an incident that occurred in China described in Howard Gardner's (1999) excellent book, *The Disciplined Mind*:

> My wife and I were visiting Najing with our eighteen-month-old son, whom we had adopted from Taiwan when he was an infant. Each day we allowed Benjamin to insert the key to the key slot at the registration desk of the Jinling Hotel. He had fun trying, whether or not he succeeded. But I begun to notice that older Chinese people who happened to pass by would help my son place the key in the slot and would look at us disapprovingly, as if to chide us: "Don't you uncultivated parents know how to raise your child? Instead of allowing him to flail about and perhaps become frustrated, you should show him the proper way to do things. (p. 94)

The issue concerning a child's benefit from the aforementioned types of questions is particularly valid in light of certain learning theories that had been embraced until about 25 years ago, which perceived learning as a linear and sequential process (Zohar and Nemet, 2002). Learning was described hierarchically — progress from simple, lower-order cognitive tasks to more complex ones. Bloom (1954) and Gange (1974), Zohar and Nemet (2002) argue that complex understanding was thought to occur only through the accumulation of basic, prerequisite learning.

With regard to Feynman's story, applying such an approach would probably have prevented Melville from starting off with a problem Richard knew nothing about. However, Richard was lucky because it does not seem as if he became frustrated. On the contrary, this event impressed him so much, leaving such a positive feeling with him that even many years later he still remembered and cherished it as he expressed in his book:

> That's the way I was educated by my father, with those kinds of examples and discussions: no pressure — just lovely, interesting discussions. It has motivated me for the rest of my life, and makes me interested in *all* the sciences. (Feynman, p. 4)

In addition, "unlike the older theories, more recent learning theories see learning in a very different way. Rather than evolving from the fragmented knowledge resulting from complex ideas being broken down into smaller parts, understanding is seen as evolving while learners are engaged in thinking and inquiry in contexts that make sense to them" (Zohar and Nemet, 2002, p. 36). Posing an authentic problem that is interesting to a child, despite the fact that the child does not apparently have the necessary background knowledge to deal with it, might be a good starting point for learning. A well known such teaching strategy is termed in literature as *problem-based learning* (PBL). Problem Based Learning started at the Johns Hopkins Medical School in the early 1990s. As mentioned earlier, PBL differs from the traditional approach to teaching, where students first learn the subject matter and only then are given problems as exercises. I will provide some theoretical support as to why the PBL method might be appropriate for children, by describing two types of problems that adults as well as children encounter, namely, *well-defined* and *ill-defined*. I will then discuss two types of reasoning which people naturally utilize when solving problems; *rule-based-reasoning* (RBR) and *case-based reasoning* (CBR). Finally, I will argue that PBL encourages both RBR and CBR, as opposed to traditional teaching methods which neglect CBR. I will thus argue that PBL is an efficient learning environment, which better scaffolds inquiry skills.

Two Types of Problems: Well-Defined and Ill-Defined

There are two types of problems which people may encounter: well-defined and ill-defined problems. To explain the differences between these kinds of problems let us consider Newell and Simon's (1972) view of problem solving as a search in a metaphorical space. According to their theory, the representation of a problem consists of four elements: a description of the initial state at which problem solving begins, a depiction of the goal state to be reached, a set of operators or actions that can be taken, which serve to alter the current state of the problem and path constraints that impose additional conditions on a successful course to solution. The problem space consists of the set of all states that can potentially be reached by applying the available operators. A solution is a sequence of operators that can transform the initial state into the goal state in accordance with the path constraints. The search metaphor is most appropriate when the solver can identify a clear goal, is able to understand the initial state and constraints, and knows exactly what operators might be useful in solving the problem. These cases are considered to be *well-defined* problems. A good example of well-defined problems is a puzzle problem. The knowledge required to solve a puzzle problem is present in the statement of the problem. Children at kindergarten and primary school levels are exposed to many such situations, e.g. games such as chutes-and-ladders, dominos, checkers or chess, all of which are kinds of puzzle problems. The knowledge needed to solve the problem — winning the game — is present in the rules of the game.

However, many daily situations are often poorly defined. Not all the information they require to cope with the problem is present. It is difficult to specify the state from which one can start to identify the operators that might be applicable or even to recognize when the goal has been achieved. In other words, many daily problems are ill-defined in that the representation of one or more of the basic components — the goal, the initial state, the operators or the constraints — are severely compromised. First, let us take a problem that both adults and children face on a daily basis — how to be happy. There is no one way to reach this goal. Moreover, happiness depends on many factors. Things that would make us happy today would not necessarily make us happy tomorrow. Thus, in such a problem even the goal is not defined. Another apparently simple problem a child may face might involve playing in his/her backyard with a ball. While playing, the ball gets stuck in a tree and won't come down. Now, the child has a real problem, especially if this is the first time this has happened. Indeed, what may serve as a problem for one person may be seen as a trivial routine exercise for another (Wheatley, 1995). To cope with this problem the child can call his parents who are inside the house to get the ball for him. Upon realizing that they are busy and will only be able to come later, he has to think of an alternate course of action. He might try to shake the tree. If this still doesn't work the child might try to reach the ball by using a long stick or throwing something at the ball, dislodging it and causing it to fall. The child may also think of bringing a ladder to climb up and reach the ball. In such a problem, unlike in puzzle-like problems, the operators are not defined. The child does not know the operators in advanced and has to invent them.

Despite the fact that most problems in daily life are ill-defined, children at school are primarily given well-defined problems. According to Wheatley (1995), science and mathematics problem solving in school is thought of as the solving of highly structured word problems appearing in texts, aiming at providing practice for prescribed computational procedures. A student can usually decide which method to use by identifying the method illustrated in a preceding lesson. Consequently, one may regard most problems with which children are provided in school as well-defined ones. The author argues that such word problems do not develop students' problem solving skills. One may also find similar situations in early childhood education. Most of the time in school is invested in playing puzzle problems, teaching children to count, solving simple arithmetic problems, or asking the children questions on simple factual knowledge to check whether or not they remember what was learned. Although it is crucially important to develop such skills, it is my understanding that educators should also include ill-defined problems in their lessons. According to Wheatly (1995), in situations where problem solving is the explicit goal, non routine problems are usually selected.

Another interesting finding about problem solving in school is that developing problem-solving competence does not guarantee conceptual understanding: students may perform well with quantitative problems yet show a severe lack of understanding of the concepts that they are dealing with in these problem solving activities (Mazur, 1992). Furthermore, "several less powerful understandings allow the students to arrive at the 'correct' answer to the physics problem — correct in terms of the expected quantitative solution or algebraic expression" (Bowden *et al.*, 1992, p. 263). Mazur raises the question as to the benefit of mainly teaching the mechanical manipulation of equations without gaining understanding.

So, one question that arises from this discussion is how we, the educators, can promote the development of problem solving of both ill and well defined problems. To better understand what educators face in their efforts to promote children's abilities to deal with both types of problems it is worth understanding the two natural reasoning mechanisms which people employ when dealing with problems: Rule-Based Reasoning and Case-Based Reasoning.

RULE-BASED REASONING

Rule-based reasoning (RBR) is the process of drawing conclusions by linking together generalized rules, starting from scratch (Leake, 1996). RBR models are rooted in the philosophical belief that humans are rational beings and that the laws of logic are the laws of thoughts (Eysenck and Keane, 1995). According to Kolodner (1993), although some rules are very specific, the goal is to formulate rules that are generally applicable. An important advantage of rules in general is the economy of storage they allow (Kolodner, 1993). However, there are some disadvantages to RBR:

- The problem of applicability, i.e., bringing some general piece of knowledge to a particular situation (Mostow, 1983). When rules are expressed too abstractly, the terms tend to be unintelligible to the novice and have a variety of specific meanings to the expert.
- Ill-defined domains. In domains that are not completely understood, the rules do not encompass all of the situations that they are asked to cover or are assumed to cover, may admit tacit exceptions, or can be contradicted and annulled by other rules (Rissland and Skalak, 1991).

These characteristics of rules and RBR indicate that people should use more than RBR when solving puzzle problems, and further, facing authentic daily problems. Let's take, for instance, the game of Checkers. As explained previously, a child playing such a game is actually dealing with a well-defined problem. The goal of the game is either to capture all of the opponent's pieces or to blockade them. Different children may understand the term "capture" or "block" differently. An experienced Checkers player will probably have a broader and better understanding of what the abstract ideas "capture" or "block" mean. Moreover, the same rule might have a different meaning in the game situation. The novice also might find himself, indeed employing the rules, however with no success. When dealing with ill-defined problems this might be even worse. Going back to the ball story, it is clear that, from the child's point of view, unlike in the case of Checkers, there are no rules to which a child can refer. In Richard Feynman's story, Richard faced the same kind of situation. There were no rules available for him. This means that the idea of RBR clashes with the idea of PBL.

An underlying assumption in RBR is that abstract information is important in problem solving, while the value of knowledge of a specific event and specific experiences is neglected. This view is challenged by the personal-knowledge point of view, which views the knowledge of specific episodes as a key to successful problem solving (Cohen, 1996; Kolodner, 1993; Leake, 1996).

CASE-BASED REASONING

Personal knowledge, defined as the unique frame of reference and knowledge of self, is central to the individual's sense of self (Higgs and Titchen, 1995), and is a result of an individual's personal experiences (Butt *et al.*, 1982). Much of the knowledge used in problem solving and making judgments is tacit and individual (Carroll, 1988; Polanyi, 1962).

Case-based reasoning (CBR) takes the idea of personal knowledge one step further. In CBR, the primary knowledge source is not generalized rules or general cases, but a memory of stored cases recording specific prior episodes (Leake, 1996). A case which records knowledge at an operational level represents specific knowledge tied to a context (Kolodner, 1993). Cases may cover large or small time frames, associating solutions with problems, outcomes with situations or both (Koldner, 1993). CBR can mean adapting old solutions to meet new demands, using old cases to explain new situations and using old cases to critique new solutions. It can also require the use of reasoning from precedents to interpret a new situation or to create an equivalent solution to a new problem (Kolodner, 1993). Advantages of CBR include the following:

- It allows the reasoner to propose solutions to problems quickly, saving the time that would be necessary to derive these answers from scratch (Kolodner and Leake, 1996).
- It allows the reasoner to propose solutions in domains that are not completely understood (Kolodner and Leake, 1996). In such situations rules are imperfect. Thus, solutions suggested by cases also increase the quality of the solutions.
- It allows for avoiding making mistakes similar to those made earlier (Cohen, 1996; Kolodner, 1993; Leake, 1996).
- Reference to previous similar situations is often necessary to deal with the complexities of novel situations (Kolodner and Leake, 1996).

In our daily lives, we humans find ourselves confronting ill-defined problems or problems that are not completely understood. CBR assists us in overcoming the complexity of real-life situations. Cases, as opposed to rules, provide a large chunk of knowledge tied to a context. Cases may also contain a wide spectrum of knowledge, including sensory factors that may be ignored by rules. It can be argued that cases, as opposed to rules, provide rich index items and thus may lead to efficient retrieval of relevant knowledge from memory, particularly in ill-defined situations. CBR is especially important in childhood. First, if adults have difficulties in applying some general pieces of knowledge (a rule) to a particular situation, it would most likely be even harder for children to do so. Second, children have not yet been exposed to much in the way of formal learning and thus have not yet acquired rules that might help them in dealing with the rich situations they face in real-life. Children, therefore, are more likely to depend on specific previous cases they have dealt with in their past in order to deal with a new situation. Children who play a new game for the first time will have probably learned from their mistakes in previous specific games that they played before. In the case of the child dealing with the ball in the tree, he might remember another case of a toy stuck on a high shelf or seeing a basketball game where a ball was stuck between the ring and the board. By remembering such specific cases, the child may adapt the solution from the prior case and alter it so that its solution fits the new case.

According to Eshach and Bitterman (2003), the argument that CBR, in many situations, is more efficient than RBR leads to the idea that the recollection of cases, in some situations, is more efficient than the recollection of rules. The authors argue that there are situations where indexing a large chunk of a more specific knowledge (e.g., cases) might result in more efficient retrieval of that knowledge from memory, rather than the retrieval of small pieces of abstract knowledge (e.g., rules). One reason for this, they claim, is that cases record knowledge at an operational level and thus are more meaningful to the reasoner than the abstract knowledge of a rule. In addition, a case, as opposed to rules, provides rich index items and thus may lead to the efficient retrieval of relevant knowledge from memory especially in ill-defined situations.

PBL, as opposed to lecture-based instruction, encourages and promotes CBR. The cases provided by the PBL approach are indexed in memory by rich index items. For example, Richard Feynman may remember the case of walking in Catskill Mountain woods and seeing the birds pecking at their feathers, in a completely different situation. For instance, while learning at school about the connection between food sources and the ability of some life form to find it, or even if he himself was to take his child on walks in the woods. Many routes may lead Richard to the retrieval of this specific story. This, in turn, might assist him in confronting other situations.

To summarize, in a traditional learning environment a child begins to learn a subject by accumulating basic prerequisite rules belonging to that subject. Usually, in this stage only lower-order thinking such as mere memorization is required. Only after acquiring these prerequisites can the learning process progress and allow us to demand a higher order of thinking such as problem solving. More advanced learning environments possess an opposite approach to learning. Within such learning environments, *learning for understanding* occurs when children engage in inquiry that requires higher-order thinking, in contexts that make sense to them. I have also provided an explanation, based on cognitive psychological theories, as to why approaches such as PBL, are efficient. Specifically, I have demonstrated that PBL promotes the use of CBR; a natural reasoning technique which we humans employ throughout daily life. Factual knowledge based teaching, on the other hand, emphasizes mainly RBR which might not be sufficient in dealing with the full complexity of real life situations. Additional support for the use of problems as a starting point for teaching stems from Dewey's distinction between *logical* and *psychological* methods, discussed in the next section.

LOGICAL VS. PSYCHOLOGICAL METHODS

According to Dewey (1916), science is the outcome of observation, reflection, and testing which are deliberately adopted to secure a settled and assured subject matter. He claims that science signifies the realization of the logical implications of any knowledge and that perfecting of knowing, is its final stage. He argues that,

> . . . there is a strong temptation to assume that presenting subject matter in its perfected form provides a royal road to learning. What is more natural than to suppose that the immature can be saved time and energy, and be protected from needless error by commencing where competent inquiries have left off? The outcome is written large in the history of education. Pupils begin their study of science with texts in which the subject is organized into topics according to the order of specialist. (p. 220)

To the non-expert, however, according to Dewey, this perfected form is a stumbling block. Specifically because the material is stated with reference to furthering of knowledge as an end in itself, its connections with the material of everyday life are hidden. Moreover, acquiring the factual rules of a subject does not guarantee the ability to use them precisely when needed. This is due to the characteristics of rules as well as RBR. Dewey, with whom I agree, further argues that "from the standpoint of the learner scientific form is an ideal to be achieved, not a starting point from which to set out" (p. 220). Dewey suggests that the proper way to teach science is to begin with the experience of the learner, with what is familiar to the child and an ordinary acquaintance by him or her. This is a method which he termed the "*psychological method*," or the "*chronological method*."

> Dewy warns us that "Educationally, it has to be noted that logical characteristics of method, since they belong to subject matter which has reached a high degree of intellectual elaboration, are different from the method of the learner — the chronological order of passing from a cruder to a more refined intellectual quality of experience. When this fact is ignored, science is treated as so much bare information, which is less interesting and more remote than ordinary information, being stated in an unusual and technical vocabulary" (p. 230).

Referring to Feynman's story again, one can see that Melville employed the psychological method by beginning the teaching process with an authentic problem that he thought might be of interest to his son. He could "save" time by beginning with the factual rules, and then explaining how the pecking phenomenon can be understood by these rules. However, considering Richard's needs, he understood the necessity of challenging him in order to develop in him an intrinsic motivation and desire to learn.

SCAFFOLDING

Another educational issue that is well demonstrated in Feynman's story is *scaffolding*. The scaffolding metaphor first appeared in Wood *et al*'s (1976) paper *The Role of Tutoring in Problem Solving*. According to this metaphor adults are said to provide a *scaffold*, much like that used by constructors in erecting a building, when their assistance "enables a child or novice to solve a problem, carry out a task or achieve a goal which would be beyond his unassisted efforts" (Wood *et al.*, 1976, p. 90). In this paper no explicit reference to Vygotsky's developmental theory (1978) has been made. However, subsequent work, beginning with Cazden (1979), increasingly linked scaffolding with Vygotsky's notion of the zone of proximal development (ZPD). The ZPD is defined as the distance between what individuals can accomplish alone and what they are able to accomplish when assisted by a more capable peer. The increasing use of the scaffolding idea reflects a growing disenchantment with what might be called the individual-child-learner model of development, made popular by followers of Piaget (Stone, 1998). As opposed to Piaget's developmental theory where there is no emphasis on the role of social relationships on the child's accommodation processes, Vygotsky's theory implies that social relationships underlie all higher mental functions. Vygotskian's theory maintains that activities and experiences become internalized only after a series of transformations which initially take place between people (interpsychological) and are then directed inward (intrapsychological), meaning that dialogue with others becomes internalized and part of an individual's inner thoughts (Jones *et al.*, 1998).

Wood *et al.* identified six types of assistance which the adult tutor can provide: recruitment of the child's interest, reduction in degrees of freedom, maintaining goal orientation, highlighting critical task features, controlling frustration, and demonstrating an idealized solution path. Stone (1998) suggests that this list includes perceptual components (e.g. highlighting task features); cognitive components (e.g. reducing degrees of freedom); and affective components (e.g. controlling frustration). Other complementary types of assistance that are worthy of mention are those of Carter and Jones (1994): prompting, modeling, explaining, asking leading questions, discussing ideas, providing encouragement, and keeping the attention centered on the learning context. Returning to Feynman's story, one can identify some of the above types of assistance: *recruitment of the child's interest* — Richard's father began by referring to the birds by different names. I believe that this was done with a sense of humor that, in itself, probably invited Richard into the adventure his father was conspiring. In addition, his father declared that knowing the birds' name provides no information whatsoever about the birds. This, I assume, may have increased his son's motivation to begin to wonder about the "real thing," which extends beyond the name. After this motivating introduction there is a direct invitation — So let's look at the bird and see what it's doing — that's what counts. *Reduction in degrees of freedom* — after the invitation to discover what the birds are doing comes a reduction in the degrees of freedom — not to look at all of the bird's behavior, but rather focus only on how it pecks at its feathers. Asking leading questions — after Richard hypothesizes that birds peck at their feathers to straighten them out after flying, Richard's father leads his son to examine this hypothesis by attempting to answer whether or not birds peck more just after they land. Through this teaching process, it is apparent that the father has a clear goal toward which he *maintained orientation* to reach his son the principle that "wherever there's a source of food, there's some form of life that finds it." For this goal, he gave his son with scientific *explanations*.

Use of a good metaphor may help people gain insights about a phenomenon. Indeed, the scaffolding metaphor explicitly reveals the role the teacher takes in the teaching-learning process, which aims at facilitating optimum learning (Fleer, 1992). Teachers should "have an image of scaffolding as a complex social process of communicational exchange and conceptual reorganization through which knowledgeable others foster understandings and capabilities" (Stone, 1998).

SITUATED LEARNING

Situated learning is another educational topic related to Feynman's story. The main tenet of situated learning, which focuses on the relationship between learning and the social situations in which it occurs, is that learning is a process that takes place in a participation framework, as opposed to in an individual mind. As William F. Hanks puts it in his introduction to the Lave and Wenger book *Situated Learning: Legitimate Peripheral Participation*, the individual learner does not gain a discrete body of abstract knowledge which (s)he will then transport and reapply in later contexts. Instead, (s)he acquires the skill to perform by actually engaging in the process, under the attenuated conditions of *legitimate peripheral participation* (LPP). According to LPP, "learners inevitably participate in communities of practitioners and the mastery of knowledge and skill requires newcomers to move toward full participation in the socio-culture practices of a community" (Lave and Wagner, 1991, p. 29). Learning is not the acquisition of knowledge by individuals as much as a process of *social* participation. This contrasts with most traditional classroom teaching that usually involves out of context abstract knowledge. Learning through LPP occurs no matter which educational form provides the context for learning, or regardless of whether there is any intentional education at all. This view point provides a fundamental distinction between learning and intentional instruction. Such decoupling does not deny that learning can take place where there is teaching, but does not take intentional instruction to be by itself the lone source or cause of learning.

Feynman's story is connected to the idea of situated learning because, first, the learning took place in a participation framework — father and son. Second, the learning process was in context, during the actual watching of the birds. Finally, it is reasonable to assume that the learning was unintentional. After all, Richard and his father did not set out on their walk with the purpose of learning about birds, but rather to engage in some quality time together.

So far I have used Feynman's story to describe educational approaches that may fit early childhood science education. Next I will describe some additional educational strategies for those who want to teach science to young children.

LEARNING THROUGH PROJECTS

There are many advantages to problem-based learning (PBL). There are different methods by which one can apply the PBL approach. For instance, Feynman's story is a single short episode activity. Other PBL activities may last longer. The renowned Reggio Emilia preschools in Italy, for example, apply a project-based learning system. In this environment, groups of children spend several *months* exploring a theme of interest such as sunlight, rainbows, raindrops, shadows, the city, ant farms, poppy fields, an amusement park for birds built by the youngsters or the operation of a fax machine. The children approach these objects, themes and environments from many angles. They ponder questions that arise in the course of their explorations and they end up creating artful objects that picture their interests and their learning such as drawings, paintings, cartoons, charts, photographic series, toy models, or replicas. When the exploration of the theme comes to a close the objects that have been created are placed on display so that parents, other children and members of the community can observe them and learn from them. The following example is taken from Gardner (1999):

> The Rainbow
>
> Suppose that in the middle of a school day a rainbow appears. Either a child or a teacher notices the rainbow and brings it to the attention of the others. The youngsters begin to talk about the rainbow and, perhaps at the suggestion of a teacher or on their own initiative, a few children begin to sketch it. After the rainbow disappears, the children would probably want to know what happened to it; where it came from and where it went after disappearing. This could well be the first stage in which the children identify both an interesting theme to be explored and are able to derive related and relevant problems to inquire about. In the next stage, the children start collecting data to answer their problems. One of the children might pick up a prism that happens to be nearby and look at the light streaming through it. She might then call over her classmates and they would begin to experiment with other translucent vessels. The next day it rains again, but afterwards the sky is cloudy and no rainbow is visible. Henceforth the children set up observational posts after a storm to guarantee that they will be able to spot the rainbow when it next appears and capture it through various media. If no rainbow appears, or if they fail to capture its appearance, students will confer as to the reasons why and consider how to prepare for better rainbow sighting. This would all mark the beginning of a project on the rainbow. In the following weeks, children gain a common interest in researching rainbows and read and write stories about them, explore raindrops, consider rainbow-like phenomena that accompany lawn hoses and mist, and play with flashlights and candles, noting what happens to the light as it passes through various liquids and vessels. The project does not start off with a specific goal and no one knows where it will eventually land. Also, while previous projects may influence the guidance given by the teacher, this open-ended quality is crucial to the educational milieu that has been established over the decades at Reggio.

Criticism of the Reggio Approach

In the early 1990s, Newsweek declared that the preschools of Reggio were the best in the world. Referring to this declaration, Howard Gardner writes "in general I place little stock in such rating, but here I concur" (p. 87). So the reader may justifiably ask how the author of this book dares to criticize this wonderful approach. I definitely agree that the Reggio approach is unique. However, approaching the topic from the teachers' perspective, I would argue that the projects which might seem sound at first, might not be congruent with the teachers' qualifications and needs. To deal with rainbows, teachers must have decent knowledge about them. They should know about the connection between a rainbow and light streaming through a prism — a very difficult concept for kindergarten teachers to understand, being as they do not usually have sufficient scientific background. I have no doubt that in Reggio this approach works wonderfully. However, if our aim is to expand this approach we might find it difficult to implement. It is my view that teachers who have insufficient background might teach the scientific ideas so terribly wrong that it would be extremely hard to alter at a later stage. In many cases, unlike the superior conditions at Reggio Emilia, a kindergarten teacher usually works alone, without many opportunities to learn from colleagues and experts.

I thus argue that educators should seek after such activities that not only fit the children's needs but also the teachers' abilities, motivations, and needs. To summarize this point, the Reggio Emilia's project-based approach sufficiently considers the child's needs. Moreover, it may even contribute tremendously to the children's cognitive development. But to succeed in using such an approach, a kindergarten teacher must receive sufficient scientific support. Without such support, one may not only miss the approach's goal, but may also unintentionally lead students to misconceptions. Thus, I argue that K-2 science education should be teacher-centered as well as student-centered, as opposed to the traditional student-centered approach. This subject will be further discussed in depth in Chapter 4. Nonetheless, projects chosen with care may fit the kindergarten environment.

In all the above teaching approaches, both verbal and non-verbal representations are used. However, non-verbal representation deserves more focus, to understand how educators should deal efficiently with such representations in their teaching environments.

NON-VERBAL KNOWLEDGE

The Case of Body Knowledge

According to Dewey, mind and body have been perceived by educators as separate entities that may even interfere with each other. According to this notion, bodily activity is considered by educators as an intruder that,

> having nothing, so it is thought, to do with mental activity, it becomes a destruction, an evil to be contended with. For the pupil has a body, and brings it to school along with his mind. And the body is, of necessity, a wellspring of energy; it has to do something. But its activities, not being utilized in occupation with things which yield significant results, have to be frowned upon. They lead the pupil away from the lesson with which his "mind" ought to be occupied; they are sources of mischief. (Dewey, 1916/1966, p. 141)

In a conference I attended, conducted in Birmingham, England, we were taken for a tour of an old coal mine, which has now become a very interesting museum. In the museum which showed how people lived in those days, a small typical class was presented. The objects which drew my attention were the children's chairs and desks. The chairs were connected to the desks so that the children could not change the distance between the chairs and the tables. The tables were split into two parts. In order for the children to sit in their chairs they had to lift one part of the table. After sitting in their seats they let this part of the table back down. Now, it seemed as if they were "locked" in their seats. This structure of the chair and desk well demonstrates the view according to which teachers should suppress their pupils' body during lessons so that the children's bodies do not disturb their minds. Dewey argues that "it would be impossible to state adequately the evil results which have flowed from this dualism of mind and body, much less to exaggerate them" (p. 141). The importance of bodily knowledge is supported currently by cognitive psychology theories where non-verbal mental representations of knowledge in memory, in different modalities, account for how we think and are at least as fundamental as verbal presentation. There is a growing awareness that *bodily knowledge*, which is the kind of knowledge reflected in motor and kinesthetic acts (Reiner and Gilbert, 2000), is "stored" in our body and impacts our behavior. For instance, each one of us has probably experienced not being able to remember a phone number unless we actually dial the number using the phone's key-pad itself. It is as if our fingers 'know' the number better than us. The knowledge of the phone number is somehow embedded in our body. Another example is the knowledge embodied in ball games such as snooker or basketball. Consider for example snooker players. Experienced players know that if they want the ball they hit with their cue stick to stop after clashing with another ball, they should aim their cue stick at the exact centre of the ball. They know that if they want the hitting ball to bounce back, then they should direct the stick to hit the lower part of the ball. They are also aware of the fact that in order to enable the initial ball to continue rolling forward (in the same direction of the ball being clashed) they should direct the stick to the upper part of the ball. In the same manner, a basketball player knows what amount of force and the direction he or she needs to apply to the basketball so that it will enter the basket. These examples demonstrate that body knowledge is a knowledge that we cannot ignore. According to Dewey,

> Before the child goes to school, he learns with his hand, eye, and ear, because they are organs of the process of doing something from which meaning results. The boy flying a kite has to keep his eye on the kite, and has to note the various pressures of the string on his hand. His senses are avenues of knowledge not because external facts are somehow "conveyed" to the brain, but because they are used in doing something with a purpose. (p. 142)

This idea is also supported by Piaget's cognitive development theory (Piaget *et al.*, 1952). One basic assumption underlying Piaget's theory is that the origin of thinking is in sensomotorisch activity (kinesthetic experience) of the physical surroundings. In the process of cognitive development, sensomotorisch activity is assimilated and then appears in the form of mental operations in the stage of concrete operations at the ages of 6–7.

Sometimes we are not aware of our body knowledge (Henry, 1953). For instance, having aquired a particularly high level of skill, an athlete seems to disconnect bodily performance completely from overt cognitive control and the body 'takes over' (Starkes and Allard, 1993). Reiner and Gilbert (2000), referring to the work of Starkes and Allard (1993) argue that it seems as if the body 'knows' something the player 'does not' Rather than rational propositional knowledge being used some sort of imagistic, embodied form of knowledge, which is not 'registered' in the conventional manner, is being employed.

There are some studies supporting the impact of body knowledge on the understanding of the learned subject. Helm (1991) studied the effects of learning modalities and found that kinesthetic subjects attained the highest grade averages. Prifster and Laws (1995) described experiments that are possible with kinesthetic devices which help eradicate some of the traditional student misconceptions and provide students with a deeper understanding of basic physics concepts such as Newton's laws. Clement's (1988) findings also support this view in that he showed that embodied intuitions about forces have a role in understanding physics situations. He suggests that knowledge embodied in perceptual motor intuitions is used for physics problem solving by experts.

In her interesting research, *Effects of the Kinesthetic Conflict on Promoting Scientific Reasoning*," based on Piaget's original work, Druyan (1997), tested the effect of kinesthesia on children's learning. Here I will describe experiment 1 of her study concerning the concept of length. Before the intervention, the participants were given two drawings of two paths that had the same starting and ending points. One of the paths was a straight blue path 10 cm long, and next to it was a zigzagged green path 15 cm long. At the start of each path was a picture of a child, and at the end of each path was candy. The subjects were told that the children in the drawing want to reach the candy at the end of their path. Each child claimed that his path was the shorter one, and a third child, standing on the side claimed that the two paths were equally long. The children were asked to decide which one of the children was correct. Was one path shorter than the other or were they equal in length? Those of the children who did not answer correctly on this task were randomly divided into the following three groups:

1. Walking training — the children were asked to walk on a zigzag path (15 m) and a straight (10 m) path.
2. Jumping training — the children were asked to jump on both legs along each of the paths (as in 1).
3. Measured Walking with Peer — each pair of children was asked to walk heel to toe simultaneously along the paths in a pace that was determined by a drumbeat: one on the straight path and the other on the zigzag path (as in 1 and 2), after which they changed places.

After each task the children were asked which of the two, the straight or the zigzag paths, was more difficult.

The posttest included the pretest and two other similar tasks: a straight path with a curved path and a straight path with a broken path. The findings of the experiment suggest that the jumping and the kinesthetic measuring tasks (and not the walking — which is an effortless task) were efficient in promoting the concept of length. According to the author,

> Transferring the change in perception of the concept of length from kinesthetic to a more formal level of presentation such as paper task and to other different patterns indicates a high level of cognitive change achieved through effort-involved training. . . . The advantage of measured walking over normal walking supports the attitude which relates the importance of measuring activity in the thought process. . . . activating the body simultaneously with measuring length might create more significant brain connections. (p. 1089)

Educators should be aware of the importance of body knowledge. They should provide the children with appropriate sensomotorisch experiences which can then be used as an established basis upon which the correct scientific concepts may be built. For instance, as in Druyan's work, exposing children to following efficient kinesthetic experiences like jumping training or measured walking with peers might help children gain a better understanding of the concept of length. And as Duryan puts it, "To improve science teaching, teachers are encouraged to be more creative in developing and using active strategies for learning" (p. 1089).

Use of Visual Representations

I started the section on non-verbal representation with the concept of body knowledge and argued that a teacher who is aware of the impact that body knowledge may have on the construction of concepts, should design his or her lessons accordingly to take full advantage of kinesthetic experiences to promote the learning process. Body knowledge is one kind of non-verbal representation of knowledge. *Visual representations* may also impact the learning processes. To gain a good understanding of visual representations and learning processes, one must understand the difference between external and internal visual representation as well as the relationships between them. Visual representations of every day life include writing, pictures, and diagrams. A visual *mental* representation, or *imagery* is defined as the "mental invention or reaction of an experience that in at least some respects resembles the experience of actually perceiving an object or an event (Finke, 1989). According to Thomas (1999) imagery is a quasi-perceptual experience: experience that significantly resembles perceptual experience (in any sense mode), but which occurs in the absence of appropriate external stimuli for the relevant perception. Imagery is the process by which humans represent knowledge in their minds. According to Kosslyn (1994), imagery is a basic form of cognition and plays a central role in many human activities ranging from navigation to memory to creative problem solving. The following are classes of imagery abilities (Kosslyn, 1994):

1. Image generation and maintenance — there are three ways in which visual images are created. First, one can recall a previously seen object or event. Second, one can combine objects in novel ways. Finally, one can visualize novel patterns that are not based on rearranging familiar components; one can "mentally draw" patterns that he/she has never actually seen. Once the image is created it can also be retained in one's working memory.
2. Image inspection — people can scan an image and 'zoom in and out' to see different parts of that object.
3. Image transformation — The classic research of Shepard, Cooper, and their colleagues (Shepard and Cooper, 1982; Shepard and Metzler, 1971) demonstrated that not only do mental images exist but also that there are mental operations that

can transform them in various ways. People can mentally rotate objects in images. It was found that people can also "mentally fold" objects in images and otherwise transform them (Shepard and Feng, 1972). In addition, it appears that imagery and perceptual tasks in the same mode would often mutually interfere with one another (Brooks, 1968; Segal, 1971).

This indicates that "visual images have all the attributes of actual objects in the world — that is, they take up some form of mental space in the same way that physical objects take up physical space in the world, and that these objects are mentally moved or rotated in the same way that objects in the world are manipulated" (Eysenck and Keane, 1995, p. 215).

Mental representations are generated from our memories of past perceptual experience, and they develop and change as a result of interaction with present sensory input (Kosslyn, 1994). Thus, what we are able to represent in our memory system is often limited by what we have perceived. Stated differently, there is a connection between a human's ability to construct internal visual representations and the external visual representations to which they were exposed. It is clear that by providing students with efficient external visual representations, educators may help them construct mental visual representations. Such representations may assist them tremendously in dealing with novel problems with which they are confronted. Monaghan and Clement (1999, 2000) found that external visual representations experienced through the use of on-line computer simulations of relative motion, facilitated mental simulation off-line and improved problem solving.

Support for the idea of visual imagery is provided by historians of science who argue that visual imagery played a significant role in many scientific and technological discoveries. Gowan (1978), for instance, states that "in the case of every historic scientific discovery which was reached carefully enough, we find that it was imagery . . . which produced the breakthrough." Einstein himself once wrote, "My particular ability does not lie in mathematical calculation, but rather in visualizing effects, possibilities, and consequences" (Pinker, 1997, p. 285).

Educators should bear in mind that they must be aware of how important it is to encourage children to create efficient visual images that will contribute to their conceptual understanding. This can be done by using rich external representations such as pictures, diagrams, graphs, movies etc. In addition, an educator might also encourage children to use their imaginations to create such visual images. Here is another episode from Feynman's book, describing how Richard's father encouraged him to use his imagination:

> We had the Encyclopedia Britannica at home. When I was a small boy he [the father] used to sit me on his lap and read to me from the encyclopedia. We would be reading, say, about dinosaurs. It would be talking about the Tyrannosaurus Rex, and it would say something like, "This dinosaur is twenty-five feet high and its head is six feet across."
>
> My father would stop reading and say, "Now, let's see what that means. That would mean that if he stood in our front yard, it would be tall enough to put its head through our window up here." (We were on the second floor.) "But his head would be too wide to fit in the window." Everything he read to me he would translate as best he could into some reality.

> It was very exciting and very, very interesting to think there were animals of such magnitude — and that they all died out, and that nobody knew why. I wasn't frightened that there would be one coming in my window as a consequence of this. But I learned from my father to translate: everything I read I try to figure out what it really means, what it's really saying. (Feynman, 1988 p. 2)

In the next section, I introduce two visually-based teaching methods: conceptual models and concept maps. Both methods, if used in K-2 appropriately, may contribute to children's construction of meaningful scientific as well as non-scientific concepts.

Conceptual Models

A conceptual model is defined as words and/or diagrams that are intended to help a learner build mental models of the system being studied; a conceptual model highlights the major objects and actions in a system as well as the causal relations among them (Mayer, 1989, p. 43).

According to Mayer, conceptual models:

1. Guide students' selective attention toward the conceptual information in the lesson (i.e. the major objects, states, and actions, and the causal relations among them).
2. Organize the information around coherent explanations (i.e. build internal connections).
3. Integrate the information with existing relevant knowledge (i.e. build external connections).

Students given conceptual-model-based instruction may be more likely to build mental models of systems that they are studying and to use these models to generate creative solutions to transfer problems.

One example is Mayer *et al.*'s (1984, Experiment 1) research. High school students who studied physics were asked to read a 450-word passage on density. Some students were provided with conceptual models whereas others were not. The model showed a diagram of a cube of city air along with a verbal definition of volume and diagrams showing particles in a cube of city air along with a definition of mass. It was found that the students with the model recalled 144% more of the conceptual information, scored 26% lower on verbatim retention tests and solved 45% more of the transfer problems than the control students. In a review article Mayer (1989) argues that since models help students direct their attention toward the conceptual objects, locations and actions described in the lesson, students will improve their conceptual retention. In addition, since models help students reorganize material, they tend to lose the original presentation and will reduce verbatim retention. The most crucial finding about models is that they improve the ability of students to transfer what they have learned to creative solutions of new problems. "The ability to generate novel solutions to new problems is the hallmark of systematic thinking; if students have built models that they can mentally manipulate, they will be better able to solve transfer problems" (p. 59).

For example: while explaining plant growth to a class, a teacher can make excellent use of conceptual models by showing children pictures of a plant in different stages of its growth, with supporting text under each picture. This combination of visual presentation along with text creates a conceptual image like those described by Mayer. For K-2 children, the wording with each image should be as simple as possible. This case would also familiarize the children with the appropriate wording. The teacher may even decide to divide the children into groups and give each of them a different picture, each of a different stage of the growth process. The children can then be asked to put the pictures in the correct order, giving them a chance to participate.

Concept Maps. The concept map, which is a graphical hierarchical representation that links related concepts to form chains of relationships, was developed by Novak in 1977. A concept map contains nodes and labeled lines. Nodes are usually depicted with circles drawn around a term or a concept. The lines between the nodes show which concepts are related. Specific relationships between two concepts are indicated by linking words that are written along the connecting lines. The labeled lines link the concepts to form propositions. These propositions are essential to representing concept/propositional meanings in an explicit hierarchical framework. Novak (1990) argues that concept maps may improve science education in the following four categories: (1) as a learning strategy, (2) as an instructional strategy, (3) as a strategy for planning curriculum, and (4) as a mean of assessing students' understanding of science concepts. This chapter is concerned with the first two categories. First, I will describe the power that concept maps may have on science education. Later, I will argue that using concept maps in their regular forms in K-2 may be problematic. Taking into account the fact that younger children are limited in their literacy skills, I will present a novel way in which concept maps may be used even in kindergarten. I call them *pictorial concept maps*.

The Power of Concept Maps. To understand why a concept map is a useful tool which may tremendously improve teaching and learning, one should first understand how knowledge is mentally represented. It is well known that conceptual knowledge is highly interrelated in nature (Heit, 1997). In addition, people's conceptual structures are widely believed to bear the general properties of hierarchies (e.g. Markman and Callanan, 1983). According to Berlin (1992), hierarchical structures appear to be a universal property of all clusters' categories of the natural world. A hierarchy is a special kind of network in which the only relation allowed between category members is the set inclusion relation. For example, the set of animals includes the set of fish which includes the set of trout which includes the set of rainbow trout (Murphy and Lassaline, 1997). Set inclusion is sometimes called the IS-A relation (Collins and Quillian, 1969): A Mercedes IS-A car and a car IS-A vehicle. The IS-A relation is asymmetric: all cars are vehicles but not all vehicles are cars. In addition, the category relations are *transitive*: all dogs have warm blood, all warm blooded animals are mammals; therefore all dogs are mammals. These properties of hierarchical descriptions enable learning. For instance, if a child learns something about animals in general he or she may now generalize this to the many categories that are under animal in the hierarchy (Murphy and Lassaline, 1997). According to the authors, by being able to place a category into its proper place in the hierarchy, one can learn a considerable amount about the category.

Concept maps indeed are based on the epistemological idea that concepts and concept relationships (i.e. propositions) are the building blocks of knowledge and that internal representations of knowledge are connected in some useful way. The theoretical rationale upon which concept maps are based, according to Novak, are the following two ideas from Ausubel's theory of cognitive learning: (1) new concept meanings are acquired through assimilation into existing concept/propositional frameworks, meaning that new learning occurs through the derivative or correlative *subsumption* of new concept meanings under existing concept/propositional ideas. Indeed, teachers may use concept maps to, "tap into a learner's cognitive structure and to externalize, for both the learner and the teacher to see, what the learner already knows" (Novak, 1984, p. 40). (2) Cognitive structure is organized hierarchically. Constructing concept maps permits one to begin with the most general, most inclusive concept and to show propositional structures in a hierarchical arrangement. In addition, "Learning of concepts is becoming meaningful when we are able to draw relationships between these concepts and other concepts. In fact it is reasonable to assume that the unit of meaningful learning is two concepts plus the linking word(s) that form a proposition, and that the concept meaning grow, differentiate (i.e. become more explicit relatable to more examples), and gain in sophistication as they become embedded in larger and more diverse propositional frameworks" (Novak and Musonda, 1991).

Considering the previously mentioned idea that there is a connection between external and internal visual representation and the unique characteristics of concept maps, it is reasonable to assume that exposing children to concept maps and/or encouraging them to create ones of their own may contribute to their ability to discover connections between concepts and gain a deeper understanding of the subject at hand. In other words, a child who sees the connections between different concepts may also build an efficient coherent internal mental representation of the subject. In addition, I agree that concept maps may also help students to "learn how to learn" and take charge of their own meaning making (Novak, 1985).

According to Symington and Novak (1982), primary-grade children can develop very thoughtful concept maps which they can explain intelligently to others. But what if we wish to present kindergarten and first grade children with the idea of concept maps? At these ages the limited ability of children to read and write may pose a severe barrier to their use. To overcome this barrier I will introduce the idea of pictorial concept maps.

Pictorial Concept Maps. To overcome the existing literacy barrier with kindergarten and first grade children, the concept maps in these cases should involve visual representations of the subjects. Pictorial Concept Maps maintain all the characteristics of the normal concept maps, but they also add graphical representations to the written words. Figure 2a describes a simple concept map of a tree. Adding pictures to the concept map, as shown in figure 2b, transforms it into a pictorial concept map. The addition of pictures is crucial in making the concept maps usable with children of this age. For instance, the graphical presentation of the tree parts helps the children gain a concrete sense of their meanings, along with their names, which are written underneath the pictures. This way, a connection is made between the written term and the part itself. The pictures also enable the child to construct a hierarchal knowledge structure of the subject.

Analogical Reasoning

The idea of visual representation is well connected to analogical thinking. Analogical thinking refers to situations in which people are confronted with problems for which they do not have any directly relevant knowledge. In such cases people may apply knowledge indirectly by making an analogy to the problem. Analogies are usually visualizable and imaginable. Analogical thought involves a mapping of the conceptual structure of one set of ideas (called a base domain) into another set of ideas (called a target domain). In his book *The Society of Mind* Minsky (1985, p. 57) writes,

> How do we ever understand anything? I think by using one or another kind of analogy — that is, representing each new thing as though it resembles something we already know.

I mentioned earlier that Einstein's ability was in visualizing — "certain signs and more or less clear images, which can be 'voluntarily' reproduced and combined" (Hadamard, 1945). He called such thinking "thought experiments." One may recognize analogical thinking in Einstein's thought experiments. For example, he would imagine a man in a falling elevator and then try to see what would happen to the keys in the man's pocket (Rico, 1983, p. 71). This helped Einstein map the conceptual structure of the keys into his theory of relativity. Another example is the discovery of the benzene structure. Kekule saw the benzene ring as a reverie of snakes biting their tails (Pinker, 1997). He mapped the snake images into the benzene structure. All these analogies are visualized in some sense.

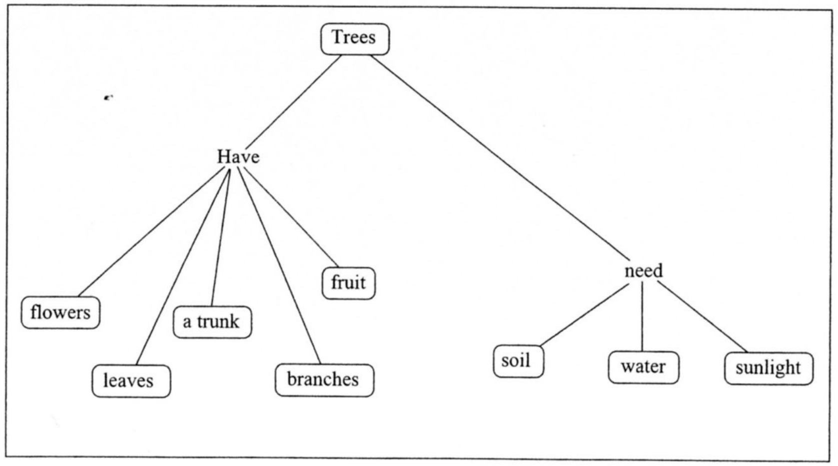

Figure 2a. The tree concept map.

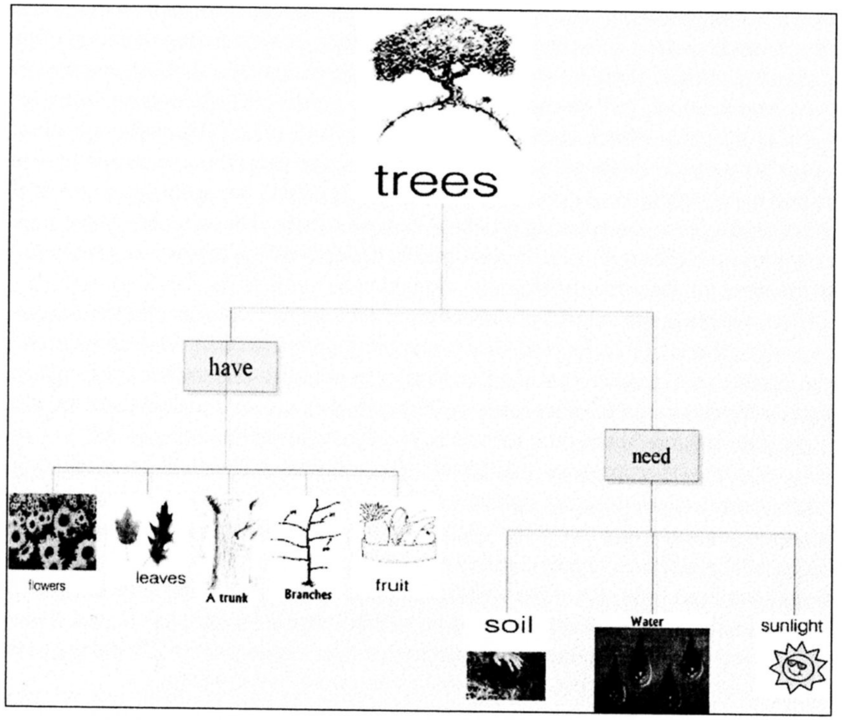

Figure 2b. The tree pictorial concept map.

According to Stavy (1991), an effective teaching tool in science which helps correct misconceptions is teaching by analogy. In this way students build on ideas which match their existing intuitive knowledge. In one of the authors' studies (Stavy, 1991, Experiment 1) children from the second, third, and fourth grades were tested individually in the understanding of inverse functions in three contexts: (1) comparing the taste of two sugar-water solutions containing the same amount of sugar but a different amount of water; (2) comparing the temperature of two different amounts of water heated by the same heat source for the same length of time; and (3) comparing the taste of equal-sized bites from two different size pieces of bread, spread with the same amount of chocolate spread. All these tasks represent ratio within different contexts. The research population consisted of the children who could not accomplish all three tasks. Half of that group was treated by being taught the role that the quantity of the water had in the concentration (taste) of a salt water solution; the other half did not receive any training. The findings showed that the children in the experimental group overcame their misconceptions and gained an understanding of inverse functions in the context of the teaching situation (concentration of a solution expressed as taste). Furthermore, they learned from this newly gained understanding to solve analogical problems in other contexts without any specific teaching. The author concluded that under suitable conditions, analogies can serve as natural mechanisms for overcoming misconceptions and learning. K-2 educators should be especially aware of the role of analogies in the learning process of a new subject. They should always search for appropriate analogies to help their pupils understand the learned materials. Take for example the following analogy.

When teaching the subject of dinosaurs, it may be difficult for children to grasp the notion of animals as large as dinosaurs being both herbivores and carnivores. In this situation the teacher can use an analogy to simplify this matter by comparing meat eating dinosaurs to other large well known animals such as lions and the plant eating ones to large herbivores such as cows or even elephants and giraffes.

An example of an analogy that should be used with care would be comparing a water current to an electric current. This analogy could create a misconception among the children due to the fact that the two currents flow in completely different manners. The electric current requires a fully closed electric circuit, whereas a water current demands little more than a pipe connecting the water source to its destination. Such an analogy could cause the children to think that it would be sufficient to connect an electric power source with a single wire (for instance to a light bulb) or even that one can pour an electric current, just as one would pour water.

DISCUSSION

In a thorough review article, Metz (1995) argues that the science curricula at elementary schools emphasizes the "concrete" with a focus on the processes of observation, ordering, and categorization of that which is directly perceivable. Within this approach, abstraction, ideas which are not tied to the concrete and manipulable, as well as planning investigations and determining their results, should in a large part be postponed until higher grades. According to the author, this approach stems from the misinterpretation of Piaget's developmental theory. Close examination of Piaget's work, Metz argues, fails to support this assumption. Elementary school children are capable of grasping some abstract ideas. "They can engage in scientific inquiry and infer new knowledge on the basis of their experimentation. Thus, it is not necessary to emphasize the process of observing, ordering, and categorizing the directly perceivable and concrete, while relegating scientific investigation to latter years" (Metz, 1995, p. 120). According to Novak (1990) there is considerable debate in the science education community as to whether or not young children are capable of understanding abstract concepts such as *energy*, *molecules*, or *evolution*. He argues that the results of his early studies suggested that the primary limitation for young children is not their "cognitive operational capacity," as indicated in the work of Piaget (1926), but rather the quantity and quality of their relevant knowledge acquired through experience and instruction. It does not matter whether or not Novak's explanation complies fully with regard to Piaget's work as suggested by Metz. The important notion to be taken from Novak's work is that with carefully designed instructions, six and seven-year-old children can acquire a useful level of understanding of *any* basic scientific concept, including concepts of energy and energy transformation, the particulate nature of matter, and the conservation of matter/energy. This concurs with Jerome Bruner's (1963) claim that any idea could be taught in some intellectually honest form to children of any age.

Taking into account the fact that children are capable of learning science, and especially that it is in the educator's hands to find good and efficient ways to teach science as early as K-2, this chapter helps shed some light on the subject. The manner by which science should be taught to children is not as obvious as might be thought at first glance. Science educators have for decades been struggling with the issue of how to implement John Dewey's (1910) call to teach science to children in a way that emphasizes method over content (Champagne and Klopfer, 1977). In this chapter I have presented some educational approaches that might help educators gain a better sense to the question, *How should science be taught to K-2 children?* In addressing this question I have presented both teaching strategies and theoretical explanations as to why these strategies should be used. I began with stressing the importance of the development of investigation skills. By doing so, I hope to represent the West's approach to teaching according to which,

> In the West we generally encourage children to try to solve problems and to contrive objects on their own. We see it a positive development when a child sports a pair of adult glasses or monkeys around with a key that is destined for a specific slot. Westerners have gained a certain hegemony in the contemporary world by exploring, trying out new approaches, experimenting and revising — whether in pursuing science and technology, or in exploring the ocean and outer spaces. (Gardner, 1999, pp. 94–95)

The idea that investigative skills may be implemented through *problem-centered* techniques such as problem-based learning, and learning through projects is explored. Problem centered learning is also congruent with *constructivisim*, which asserts, among other things, the importance that prior knowledge has in learning. Such learning environments encourage students to elaborate on their own knowledge and invite students to negotiate meaning in small group situations and then negotiate a consensus in the whole class setting (Wheatly, 1991). This also well expresses the view of those who have used constructivism according to which knowledge is personally constructed but socially mediated (Tobin and Tippins, 1993). As was mentioned in the problem-based teaching section, from Holyoak's argument in particular, it is reasonable to assume that the children who are used to being confronted with problems definitely acquire general cognitive abilities that help them deal with problems in a wide variety of domains. Introducing problems alone, however, is not enough. Scaffolding is a necessary process that helps the child build cognitive abilities. Nevertheless, scaffolding can be a vague term for an educator. In this chapter I described some scaffolding strategies. Although these strategies may help children develop problem solving skills, something else might be needed in order to address Mayer's concern. The author begins his article *Models for Understanding* with the following citation from Luchins and Luchins (1970, p. 1):

> Why is it that some people, when they are faced with problems, get clever ideas, make inventions and discoveries? What happens? What are the processes that lead people to such solutions? What can be done to help people to be creative when they are faced with problems?

The author articulates that one promising technique for helping students learn new material in approaches that allow them to be creative with problems is the use of conceptual models. This was one reason why in addition to problem-centered strategies, I chose to elaborate on the idea of none-verbal representations, of which Mayer's concept models are only a small part. I also further discuss the idea of concept maps and kinesthetics, which I believe may contribute tremendously to inculcating problem solving skills as well as to the understanding of basic scientific concepts. Comprehending these approaches might help educators enrich their scientific *pedagogical content knowledge* (PCK) (Shulman, 1987). PCK "represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction"(p. 8).

I used Feynman's story to illustrate some of the issues explored above, not because I believe that anyone that receives the same learning experience as Richard will get a Nobel Prize, nor is it because I believe everyone should be a scientist. It is my belief that by teaching by these means, we might be able to help children to exploit their full cognitive potential in whatever field they choose. The story shows that these approaches can be implemented. If Richard's father could do it, then an educator, who is exposed to novel educational ideas, should have absolutely no problem doing so as well.

Another example of how Feynman's father taught him science will also be used in the next chapter, which introduces the idea of using technological apparatus to teach science.