CHAPTER 3

WHEN LEARNING SCIENCE BY DOING MEETS DESIGN AND TECHNOLOGY

LEARNING BY DOING

I hear, I forget. I see, I remember. I do, I understand. (a Chinese proverb)

According to Schank (1996) there is only one way to learn how to do something and that is simply to do it. If you want to learn to play checkers, solve a mathematical problem, prepare a pizza, drive a car, or design a building you must have a go at doing it. Humans are natural learners. They learn from everything they do. This is probably what Dewey had in mind when he wrote,

> Thinking is the accurate and deliberate instituting of connections between what is done and its consequences. . . . The stimulus to thinking is found when we wish to determine the significance of some act, performed or to be performed. (Dewey, 1966/1916, p. 151)

The notion of learning by doing somehow challenges the old philosophical belief that humans are rational beings and that the laws of logic are the laws of thought. According to this view, if we humans are rational, it would be enough for us to learn abstract concepts and rules in order to apply them to a variety of situations which we encounter in everyday life. Also, *doing*, along with when and where we experience a situation where rules or concepts apply would have little, if any impact on the learning process. In other words, knowing the concepts and rules, which contain small pieces of knowledge and thus allow economy of storage, could be enough for dealing with all of the situations where the learned concepts and rules may be used. This is exactly what *rule-based reasoning* is. However, it has been found that people have difficulty applying concepts and rules to particular situations. One reason is that concepts as well as rules are expressed too abstractly and may be unintelligible. It is the *doing* in a context which makes the concepts and the rules we learn meaningful to us. Learning by doing finds support also in the *case-based reasoning* theory. According to case-based reasoning, reasoning is a process of retrieving examples rather than applying rules. In terms of case-based reasoning, by *doing* we acquire experience, or more specifically — cases which, as opposed to rules, contain large chunks of knowledge which are tied to a context.

> Experiences, or cases, are a critical element in understanding what is learned when one learns by doing . . . a learner is interested in acquiring sufficient cases such that he can learn to detect nuances. He wants to be in a position to compare and contrast various experiences. To do this, he needs to have had those experiences, and he needs to have properly labeled those experiences. The labeling process is what we refer to as indexing. (Schank, 1996)

The more cases we acquire, the index we will construct will be better, richer, and more efficient. This will eventually lead to a better remembering of an old case to use for decision-making with a new case.

Lave and Wenger's *situated learning* theory also supports the notion of doing in learning. Here, individual learners do not gain a discrete body of abstract knowledge which they can then transport and reapply in later contexts. Rather, they acquire the skill to perform by actually engaging in the process. Initially, people have to join communities and learn at their peripheries. As they become more competent they advance closer to the 'centre' of that particular community. Thus, according to the situated learning theory, it is irrelevant to talk of knowledge that is decontextualized, abstract or general. The nature of the *situation* impacts significantly on the process. Lave and Wenger illustrate their theory by observing different apprenticeships: Yucatec midwives, Vai and Gola tailors, US Navy quartermasters, meat-cutters, and non-drinking alcoholics in Alcoholics Anonymous. For instance, the Yucatec Mayan midwives learners in Mexico were usually the daughters of experienced midwives, with knowledge/skills being handed down within the families. The learning process was informal and part of daily life.

Schank (1996) argues that since learning by doing is how we naturally learn in real life, motivation is never a problem. We learn because something makes us want to know. What does this all tell us about education? It tells us that when designing a curriculum, we must keep in mind what it is that we are trying to have students who will go through that curriculum be able to do. To put it another way, we need to transform all training and education to make it look, and feel, like doing. However, according to Schank, there has always been a great deal of lip service given to the idea of learning by doing, although not much has been done about it in practice. The author cites John Dewey who, almost a century ago, wrote in his famous book *Democracy and Education*:

> Why is it, in spite of the fact that teaching by pouring in, learning by a passive absorption, are universally condemned, that they are still so intrenched in practice? That education is not an affair of "telling" and being told, but an active and constructive process, is a principle almost as generally violated in practice as conceded in theory. Is not this deplorable situation due to the fact that the doctrine is itself merely told? It is preached; it is lectured; it is written about. But its enactment into practice requires that the school environment be equipped with agencies for doing, with tools and physical materials, to an extent rarely attained. It requires that methods of instruction and administration be modified to allow and to secure direct and continuous occupations with things. (p. 38)

According to Schank (1996) education today has not changed very much from Dewey's days — it is still an affair of telling and being told. School has no natural motivation associated with it. Students go there because they have no choice. He gives two main reasons as to why learning by doing is not our normal form of science education. First, is the lack of "doing devices." The second reason is that educators and psychologists have not really understood why learning by doing works, and are thus hesitant to insist upon it. "They can't say exactly what it is that learning by doing teaches. They suppose that it teaches real life skills, but what about facts, the darlings of the 'drill-them-and-test-them' school of educational thought?" (Schank, 1996, pp. 295–296).

I do not fully agree with Schank that students go to school only because they have no choice. I believe that most children do find school to be a place where they enjoy.

They do learn a lot and school definitely plays an important role in their cognitive as well as emotional development. I also disagree with Schank that teaching in school today is an affair of telling and being told. On the contrary, huge efforts are being invested to respond to the call of national and international reports such as the American Association for the Advancement of Science (AAAS) (1993) according to which, if the next generation is to become scientifically literate, then learners need to become actively involved in exploring nature in ways that bear a resemblance to how scientists themselves do their work. This indeed concurs with Wolpert's comment that

> Science is a special way of knowing and investigating and the only way of appreciating the process is to do it. (Wolpert, 1997, p. 21)

The problem is not that schools do not encourage *doing*. Rather, as I shall show, the problem is how learning by doing is *implemented*. The following citation clarifies this argument,

> Yet, although elementary and middle schools are increasingly exposing inquiry-based or "hands-on" science, the objective of authentic experimentation is rarely pursued in school. Instead of extended and systematic work to explore a personally meaningful phenomenon or question, students in hands-on programs too often engage in a string of unrelated, one-period, 40-min . . . activities that emphasize the use of materials and equipment but are often poorly or entirely unmotivated from the student's point of view. Although there may be an overall design or plan behind the sequence, it is typically motivated by the structure of the scientific discipline. Because students do not share this understanding of the overall structure of the discipline, the logic behind the sequence may be apparent to teachers but a mystery to students. (Schauble *et al.*, 1995, pp. 132–133)

The authors argue that even a hands-on activity that occurs in a laboratory setting may be introduced to students as exercises rather than experimentations their emphasis on drill and mastery, practicing disembodied skills and the conduct of procedures with meanings which are not clear to the participants.

According to Moscovici (1998) the explanation for this situation stems from the teachers' lack of abilities. He reported that the general perception expressed by prospective elementary school teachers in his research was that they couldn't use techniques consistent with inquiry, as they were never involved as students in such processes. They also feared that their perceived weak background in science did not support such techniques. If they were going to teach science, they felt more comfortable with a series of disconnected activities, or what he called "*activity mania*."

There appears to be some confusion among three key components: learning, doing, and learning by doing. Schools may provide learning environments that do not encourage doing. In other cases, which I believe is the most common problem, schools may offer hands-on activities to their students — this is doing. This way of doing, however, is not always efficient in leading children to meaningful learning. Doing in such cases is detached from meaningful learning. Doing may contribute tremendously to learning. But, it should be taken into consideration that educators need to design efficient doing activities that will fit children's needs and indeed contribute to their learning. Fig. 1a and 1b demonstrate this situation. Fig. 1a illustrates the situation where there is doing, but it may not necessarily lead to meaningful

Figure 1a Doing Separated From Learning:
Doing without meaningful learning

Figure 1b Doing Leads to
Meaningful Learning: Learning by Doing

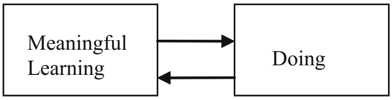


Figure 1. Relationships between doing and meaningful learning.

learning. Of course, there is always some learning achieved when doing. In such cases the potential of learning is not fully exploited. In Fig. 1b there are two arrows, one from doing to learning, and another which goes the other way around, from learning to doing. This demonstrates that in an efficient learning environment, doing may lead to meaningful learning and, in turn, we learn more and as a result can do more. I agree with Haigh *et al.* (2005), who state, "doing science has been a central theme in much international science education literature and, while there appears to be some consensus on the doing, there is less on the what for" (p. 215).

So far I have described the need to implement the *learning by doing* approach in science education. I also warned against detaching *doing* from *meaningful learning*. In other words, I argued that doing by itself should not be our aim but should rather serve learning in ways to make it meaningful. There are many ways which one can implement the *learning by doing* approach. In this chapter I will thoroughly discuss the learning of science via technology, especially through designing, building, and evaluating simple mechanical devices. It is my view, as I hope to convince the reader, that such an approach, if implemented appropriately, well fit the teaching of science both in kindergarten and primary schools. First, I shall first explain the terms *technology*, and *design*. I shall then show how one can use technology and design to enhance the learning of science.

THE TERM TECHNOLOGY

In his excellent book, *Teaching About Technology — An Introduction to the Philosophy of Technology for Non-Philosophers*, de Vries (2005) writes "I have abstained from any effort to give a definition of technology. For those who are looking for a definition there are thousands out there to choose from and I do not think I can come up with the one that beats them all" (p. 11). To gain a sense of what technology means, it is worthy to look at the term's origins. *'Technology'* derives from two Greek words: *'technē'* and *'logos'*. 'Techne' means art, skill, or craft. Specifically, a 'technē' is a skill or art that is learned, a professional competence rather than a natural talent. This means that 'technē' involves the practical skills of knowing and doing. The root 'logos' means 'word', but, particularly, a word that comes from rational thought (the Latin translation of 'logos' is 'ratio' from which we derive not only 'ratio' but also 'rational'). Thus, 'logos' can also mean speech, an account, or a discourse, as well as reason in itself. Technology, thus, encompasses reasoned application (Herschbach, 1995). Although the origin of the term technology relates to both knowledge and doing, the term "technology" in the English language, which acquired limited usage in the late 19th century, referred in those days mainly to applying science to making and using artifacts. Today, however, there is increasing emphasis on the importance of knowledge in defining technology (Layton, 1974; McDonald, 1983). de Vries (2005) takes the term "technology" in the broad sense as "human activity that transforms the natural environment to make it fit better with human needs, thereby using various kinds of information and knowledge, various kinds of natural (materials, energy) and cultural resources (money, social relationships, etc.)" (p. 11). To understand more fully the meaning of technology one should understand the relationships between science and technology.

Views Concerning the Relationships Between Science and Technology

Fensham and Gardner (1994) identified the following four possible propositions about the relationship between technology and science. The first proposition, in my opinion, considers and emphasizes mainly the practical aspect of the term technology, i.e. the *'technē'* by neglecting the knowledge component, i.e. the 'logos.' The second proposition also takes the 'logos' aspect of the term technology into account. The third and forth propositions consider both the *'technē'* and the 'logos' aspects of the term technology.

1. Science has historical and ontological priority over technology — in this view, scientific knowledge is necessary for technological capability and is acquired first. There is ample evidence for this claim. For instance, the electric industry in the 19th century and the nuclear power industry in the twentieth obviously rest on strong scientific bases. This view is well expressed in Feibleman's (1972) distinction between pure science, which uses the experimental method in order to formulate theoretical constructs, explicate natural laws, and expand knowledge; applied science which focuses on applications for purposeful activity; and technology which puts applied scientific knowledge to work.
2. Technology has historical and ontological priority over science — in this view, technological knowledge is necessary for developing scientific knowledge. There is some evidence for this claim. For instance, cannon balls launched from catapults were rounded in order to improve accuracy centuries before the physical principles of projectile motion and air resistance were formulated; Chinese built firework rockets in advance of any established theory of rocket propulsion, steel was made prior to the full understanding of the metallurgical process; and Bell's

telephone system, which was dependent on the electrical properties of carbon which were unknown to science at the time he used it. Moreover, medieval developments in clock-making laid the foundation for our modern concept of time. According to Cajas (1999) engineers use science for their specific needs. Their 'use' of science is not the simple application of universal knowledge to particular problems. Rather, they *construct* knowledge for specific situations illuminated by practical and mundane information. Further, Mitcham (1994) argues that the idea of a machine, the concept of a switch, invention, efficiency, optimization; the theories of hydraulics and aerodynamics, of kinematics and cybernetics, of queuing, information, and network theory — are all inherently technological. Such ideas are not found, according to the author, in scientific fields, but rather in technological ones. The author reaches the following rather provocative conclusion, "Indeed, the use of mechanics in science (as in Newton's "celestial mechanics") can reasonably be argued to be derived from early modern technologies (of, especially, clocks), so that science in some senses might be described as applied technology" (p. 96).

3. Technology and science are independent systems of thought and practice — Drucker (1961, in Fensham and Gardner (1994)), who proposes this view, for instance, argues that until modern times, science and technology were independent. History shows that there were cases in which artifacts and procedures co-existed with incompatible scientific beliefs. Then if an innovation was vaguely incompatible with a scientific theory, this was not necessarily disturbing. Although eyeglasses had been in use since the late thirteenth century, Galen's theory of vision, which ruled out any possibility of correcting visual defects, continued to be taught for three centuries.
4. Technology and science engage in two-way interaction — according to this interactionistic view, technologists and scientists learn from each other. This is done either over a long period of time, or contemporaneously through shared knowledge gained through social networks, or through working in close proximity on a common task. Indeed, in modern fields such as electronics, radio astronomy, computing and genetic engineering, scientists and technologists do in fact work together.

According to Roth (2001) science and technology are deeply related domains, part of a (semiotically) seamless web that integrates any distinction. To clarify this notion Roth claims that "gains in the theoretical knowledge about the telescope evolved together with gains in the understanding of its mechanical properties. Thus, Kepler contributed to the further development of the telescope by designing new types and by formulating the law of the inverse relationship between light intensity and square distance" (Roth, 2001, p. 770).

It appears that today, technology is conceived as more than artifact and or a series of techniques and processes. Technological knowledge is indeed considered to have its own abstract concepts, theories and rules, and its own structure and dynamics of change. However, one should bear in mind that (1) technological knowledge is essentially applicable to real situations and that; (2) the defining characteristic of technological knowledge is its relationship to *activity*. Technological knowledge arises from, and is embedded in, human activity. As Landies (1980) observes, while the intellect is at the heart of the technological process, the process itself consists of "the acquisition and application of a corpus of knowledge concerning technique, that is, way of doing things" (p. 11). "It is through activity that technological knowledge is defined; it is activity which establishes and orders the framework within which technological knowledge is generated and used" (Herschbach, 1995).

Surprisingly, although technology is connected to human activity, the education of technology related aspects are not always connected with activity. In many educational curricula which try to show the connections between science and technology, students are exposed to a technological system, however they are not at all required "to *do*."

In cases where *technology is learned scientifically*, we are actually missing out on a significant opportunity to learn by *doing*. It might be that the term design, which entered the scene of technology education, e.g., the Design and Technology curriculum which will be described later, emphasizes and highlights the doing aspect of technology. This is ironically the case, since the term design was originally meant to emphasize that technology is not merely a technical subject but rather a subject which requires higher order thinking, as is the case with design.

THE TERM DESIGN

The Oxford dictionary defines *design* as a mental plan. A plan or scheme conceived in the mind and intended for subsequent execution; the preliminary conception of an idea that is to be carried into effect by action; a project. From this definition one may understand that designing is reified intentional activity. This idea is well expressed by de Vries (2005) concept of *design plan* which he describes as follows,

> A designer has the *intention* of realizing a certain new artifact that can fulfill a certain function. The designer has *beliefs* about the physical properties of such an artifact and how they could make the artifact fulfill that function. Then the designer sets up a *sequence of actions*, a plan, of which (she) believes that it will result in the artifact. The designer has the *disposition to act* accordingly, and when no other considerations show up, (s)he will act accordingly. (p. 60)

The capacity for design is analogous to the capacity for language. Design ability, like language ability, reflects a capacity that everyone possesses at least to some degree, definitely not, the possession of a gifted few (Roberts, 1994).

> We all, as instances, try to create an environment which reflects our aspirations; use tools and materials purposefully; make judgments about which objects and places we like or dislike; find ourselves moved and excited by fine things that other people have made; respond to the visual messages of advertising, products, signs, buildings, films, television; and create visual images by photography and make qualitative judgments about which ones are 'successful' or which ones are 'unsuccessful'. (Roberts, p. 173)

Mental models are the 'language' of design. They contain knowledge which may be represented by propositions as well as knowledge such as sketches, drawings, and diagrams. The latter kind of knowledge, the non-propositional one, contains a richness that could never be entirely expressed in propositions (de Vries, 2005). This means that designing requires one to form mental images in his or her mind.

Mistakenly, design is often identified with one of its languages — drawings. It is important to bear in mind that design is done essentially in the mind, and making drawings or writing notes is a recording process (Report on Engineering Design, 1961). External visual representations such as drawings, diagrams, mock-ups, and prototypes may help in the design process as well as in expressing the internal process. According to Mitcham (1994) the mental effort required in the designing process is something distinct from knowing or coming to know in a scientific or theoretical (or even technological) sense, because it does not terminate in an interior cognitive act. "Designing ends with Aha! Let's make it this way. Let's go with this design" (Mitcham, 1994, p. 221).

Crismond (2001), based on the literature, argues that design, like scientific inquiry, engages the core strategies of analysis, synthesis, and evaluation, which appear as the three highest-order educational objectives in Bloom's taxonomy (1956). Acknowledging the potential that children who are exposed to design activities are likely to develop higher order thinking skills, was probably one of the reasons which led the American National Research Council to create "Science and Technology" content standards for its National Science Educational Standards, which advocates that "As a result of activities in grades K-4, all students should develop abilities of technological design" (p. 135). The report continues by saying that "This standard helps establish design as the technological parallel to inquiry in science. Like the science as inquiry standard, this standard begins the understanding of the design process, as well as the ability to solve simple design problems" (p. 135).

I started this chapter by explaining the rationale of *learning by doing*. I then suggested that one way to implement learning of science by doing is through starting the learning process by engaging students with simple mechanical artifacts. In the next section, I will argue that by neglecting to expose children to design and technology activities within science courses, educators miss a fine opportunity to teach science effectively.

APPROACHES TO TECHNOLOGY EDUCATION

In a review article, Technology education in Western Europe, de Vries (1994) summarizes eight approaches to science education. Four of these approaches that relate to elementary science education, are presented here: (1) The Craft-Oriented Approach, (2) the Design Approach, (3) the Science Technology Society (STS) Approach, and (4) the Applied Science Approach.

The Craft-Oriented Approach

Central to this is making things. Children are given work drawings in which the design has been elaborated in detail, including the materials and procedures. Most of the time is spent making work pieces. The concept of technology developed by this approach is an instrumental one: technology is a way of making things. Design does not play a role in this approach. It emphasizes the *doing* aspect of technology.

Kindergarten and primary school children usually have a good deal of experiences with this approach. For example, they build dinosaurs, cars, boats, and war hero structures using pre-designed Lego kits. In addition, children build artifacts such as wooden brick structures, dolls from cloth pieces, or cardboard cars. However, these activities are artistic in nature. They do not include all of the previously mentioned stages of design. It is my view that such activities are very important. However, as this chapter portrays, it is my opinion that children should also be exposed to some scientific concepts relevant to the structures as well as to more systematic design activities.

The Design Approach

This approach is usually an extension of the craft-oriented approach. In addition to craft-oriented activities, designing skills are also implemented. The children are provided with design problems which they have to solve in a more or less independent manner.

The Design and Technology (D&T) curriculum exemplifies this approach. It was developed in a national movement in England and Wales during the 1980s, and in 1990 the United Kingdoms' National Standards (DESQWO) added "Design & Technology" as a required subject for all students (Department of education, 1990). This approach aims to make students responsible for major decisions about: what kind of artifact or system is needed, what the product will look like, how it will work, and how it should be produced. D&T offers the potential for children to construct, apply, debate, and evaluate models, rather than simply to absorb transmitted information about them. When students engage designing, they have both the opportunity and reason to engage in cycles of model construction and revision (Lesh *et al.*, 1992). In D&T activities, students typically execute the following stages:

1. **Identifying** a need or a **problem** to be solved;
2. **Selecting** an optimal **solution**;
3. **Constructing** a **prototype**;
4. **Testing** and **redesigning**;
5. **Manufacturing** and finally;
6. **Evaluating** (Layton, 1994, See Example 1, for instance, pp. 9–10).

The Investigating and Redesigning (I&R) Approach

Recently, an interesting approach to design and technology was developed by Crismond (2001) — *The Investigating and Redesigning (I&R) approach*. It aims at offering a bridge to help students reach the steps of D&T described above. According to the author, design tasks are often frustrating for novice designers. A sequence of Investigating and Redesigning (I&R) aims at helping less experienced students avoid the feeling of frustration and futility often encountered when first doing design (Schon, 1987). According to Crismond (2001) I&R provides a scaffold via case-based reasoning (Kolodner, 1993) by giving subjects multiple exemplars of working products to investigate and analyze before redesigning. Crismond (2001) argues that with working devices in hand, naïve designers identify features and machines that can be copied or adapted. Using these methods, students can focus their attention on the overall design approach, the scientific concepts and principles embedded in the redesign challenge, rather than on the design task which is still difficult for them. In I&R activities, students are engaged in the following steps:

1. 'Messing about' with the products: **identifying** novel devices, **clustering and ranking** devices, **using** devices and **learning** about them,
2. Explaining the mode of function of these devices: **analyzing** how products work
3. Designing experiments: **listing** the features of an ideal device, **planning** a product comparison,
4. Redesigning devices: **redesigning** the device and **reflecting** on it (Crismond, 2001).

This method is particularly important for K-2 children who are definitely considered novices. A teacher may use such an approach in addition to the acceptable D&T activities. Examples are provided at the end of this chapter. The design approach emphasizes both aspects of technology — doing and logos.

The Science Technology Society (STS) Approach

This approach is an extension of the applied science approach, but pays more attention to the human and social aspects of technology. In this approach students learn that not only does technology influence both science and society, but is also influenced by them. It presents human/social and scientific aspects of technology. However, design does not always play an important role. The user's perspective is the usual approach to understanding technology (Gardner, 1992, in de Vries, (1994)). This means that the *doing* aspect of technology, which is the essence of technology, is hence ignored. Therefore, it is my opinion, that the term technology in the title, *Science Technology Society*, is misleading.

The Applied Science Approach

In this approach, the learning of scientific phenomena starts with asking questions about a certain product's functioning. This approach was developed by science educators who looked for ways to make science more relevant to students. They believed that those questions about the product's function would motivate students to learn scientific topics. However, practical work is regarded, in this approach, as less important than the cognitive elements of education. Creativity and design are almost absent. In addition, the concept which is emphasized is that technology depends strongly on science. Again, the *doing* aspect is ignored.

In the countries where this approach is executed, both the craft oriented approach and the design approach belong solely to technology education. This means that there are two different subjects in the school curriculum: the sciences — biology, chemistry and physics, and the technology. Both are subjects taught separately in the curriculum. The STS and the applied science approaches belong solely to scientific subjects. However, in such curricula, the students do not design or build technological artifacts, but rather ‘talk about them.’ This contradicts the seamless web approach according to which science and technology are deeply related domains.

Even though science includes some technological aspects and vice versa, no relation to science is portrayed in the design and technology curriculum — both are presented as separate subjects to the child. By doing so, it is my opinion that we educators, are making a mistake! We cannot on the one hand, write in academic journals that science and technology are part of a seamless web that integrates any distinction, and on the other hand teach science and the technology as two completely separate subjects, with separate teachers, separate grades, etc. In what follows I shall introduce my view that one of the ways that we should teach science is by engaging children with simple artifacts (designing and building) at the beginning of the learning process.

SCIENCE EDUCATION VIA TECHNOLOGY: A NOVEL APPROACH TO SCIENCE TEACHING

If science and technology are indeed part of a seamless web, it is reasonable to believe that technology may be learnt only after children have gained some scientific background. However, it is also reasonable to assume that the opposite is also valid. This means that one may start the learning of science from gaining some technological knowledge first. Indeed, recently, the question of whether technology-centered activities afford a learning environment that scaffolds students’ learning of science is gaining increased attention among educational researchers (e.g. Layton, 1994; Roth, 2001). Although technology is not a new player on the educational scene, the idea of teaching scientific concepts through technology is quite new. How many times has the reader seen children design, build, evaluate and redesign artifacts at the beginning of the learning process of a scientific concept within the science class? The current chapter is dedicated to the advancement of the *technology-first* approach. It is not my belief that this is the only way to teach science, but rather, that this is an efficient strategy, which educators unfortunately do not utilize in the science class. Moreover, this leads me to suggest, and I will return to this point further on in the discussion section, that we educators need to rethink how we teach science design and technology, and move towards one course — Science Design and Technology.

To get an insight of what the advantages of technology based science teaching might be, let me refer to one of Richard Feynman’s stories in his book “*What Do You Care What Other People Think?” Further Adventures of Curious Character*. The story describes how one day, as a little child, he was playing with an “express wagon,” a little wagon with a railing around it. Richard found the behavior of a ball inside the wagon to be rather interesting and went to ask his father.

> Say, Pop, I noticed something. When I pull the wagon, the ball rolls to the back of the wagon. And when I’m pulling it along and I suddenly stop, the ball rolls to the front of the wagon. Why is that?. (p. 5)

For the purpose of the current chapter I consider the wagon with the ball inside as a kind technology system that Richard investigated. The technology system caused

Richard to think of a phenomenon which appeared to be related to one of the most fundamental principles of physics. Moreover, the technology system enabled communication between Richard and his father. Both could relate to the same concrete phenomenon — the ball inside the wagon. The father even described a kind of thought experiment,

> If you look from the side, you'll see that it's the back of the wagon that you're pulling against the ball, and the ball stands still . . . . It doesn't move back. (p. 5)

In addition, Richard could immediately check his father's explanation,

> I ran back to the little wagon and set the ball up again and pulled the wagon. Looking sideways, I saw that indeed he was right. Relative to the sidewalk, it moved forward a little bit. (p. 5)

The wagon with the ball inside, indeed enabled to shuttle between the concrete (the wagon and the ball) and the abstract, as Richard's father taught him the inertia principle. This example, I believe serves as a good demonstration that Richard's learning process of the inertia principle began with dealing with a technology system. One can take this idea even one step further and think of involving the children with the designing and building of a technological system before they learn the scientific principles involved.

In a research aimed at investigating successful *science* activities, Appleton (2002) found that although many primary school teachers were reluctant to teach science — partly due to their lack of confidence and background in science knowledge — a significant number went on to explain how teaching science using "activities that work" enables them to actually teach it with some confidence. The following is a description of an "activity that works", made by Rhonda, a sixth grade teacher:

> [In] year six [the] focus is on energy, and so for one of the [activities] for the electrical energy section, they designed a car or some sort of model to work with electricity. And I extended it and they had to have a switch, which they had to make — they couldn't use a bought switch. They had to present a report on [the car project] . . . . And it really worked well, because it wasn't directed from me in any way. All they were told was, "this is what you have to have in it and design some sort of model." (p. 397)

Based on such declarations, Appleton (2002) had concluded, that although defined as "science" activities, "activities that work" have rather technological characteristics: they are hands-on, have a clear outcome or result, encourage manipulation — in order to achieve a "right" outcome, and finally — activities that work lend themselves to integration. The author argues, that "activities that work" may be a substitute or supplement to science pedagogical-content knowledge for primary school teachers, who lack other resources for attainment of such knowledge. In the next section, I shall present eight reasons as to how starting from technology is efficient when science concepts are taught.

Reasons for Technology-Based Science Teaching

1. Children tend to employ engineering models of inquiry rather than scientific models. Schauble *et al*. (1991) distinguished between two kinds of experimentation that children use when conducting scientific experiments: engineering and scientific. It is my opinion that the idea may be referred not only to experiments but also broadened to the "inquiry". So, it is my view that children utilize two models of inquiry: Engineering and scientific.

a) ***Engineering Model of Inquiry***. The child's goal in such an inquiry is to produce a desirable outcome. For this purpose the child manipulates and optimizes mostly those variables which he or she believes might impact the result and contribute to achieve the best outcome. Usually, in this type of inquiry, the inquiry reaches an end and is terminated when an outcome is achieved that meets some criterion for acceptability.

b) ***Scientific Model of Inquiry***. The child's aim in this type of inquiry is to understand the role of each variable in order to understand the relations among causes and effects. For this purpose, before reaching a conclusion, the children choose a procedure that exhaustively evaluates all of the involved variables — including those variables that they do not believe play a causal role. The inquiry process terminates in such a model only after the child has completed a systematic set of tests for every variable that could play a role in the system being investigated.

According to Schauble *et al.* (1991) " "Engineering" of this kind arguably has wider applicability to everyday purposes, and may thus be developmentally prior to the more analytic form of thinking involved in scientific inquiry" (p. 860). This might explain Appleton's (2002) conclusion, discussed previously, according to which scientific activities that work have technological characteristics. Schauble *et al.* find support for this idea in Dewey's (1913), which distinguishes between two kinds of scientific activities: practical exploration for the purpose of achieving a desired effect, and investigation for the purpose of achieving scientific understanding:

> It is commonplace that the fundamental principle of science is connected with the relation of cause and effect. Interest in this relation begins on the practical side. Some effect is aimed at, is desired and worked for, and attention is given to the conditions for producing it. At first the interest is bound up with a thoughtful effort, interest in the end or effect is of necessity transferred to interest in the means — the causes — which bring it about. (p. 83)

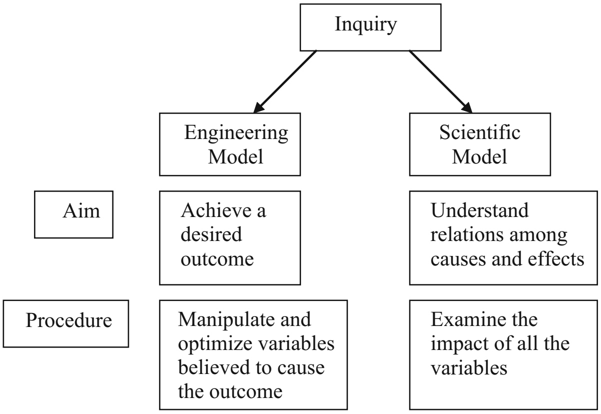


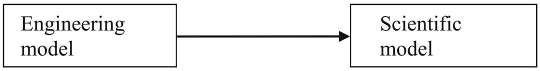
Figure 2. Differences between engineering and scientific models of inquiry.

Here are several examples taken from the literature that illustrate this point:

Tschirgi (1980) asked subjects to choose the best experiments for identifying which recipe ingredients would result in a "great cake" or a "terrible cake." He found that children predominantly chose experiments that would result in good cakes. Kuhn and Phelps (1982) presented fifth graders with the problem of trying to find out which of several chemical substances were responsible for a reaction that turned a mixture pink. Several children directed their experiments toward trying to produce the pink color instead of identifying the substances contributing to the reaction. Schauble (1990) asked her subjects to figure out which car design features affected the speed of cars. Instead of figuring out which features affected the speed, many children became preoccupied with constructing fast cars.

In another study, Schauble *et al.* (1991) asked their subjects to solve two problems by means of self-directed exploration, one designed to elicit the engineering model — the canal task and the second designed to elicit the science model — the buoyant force task. The canal problem was concerned with the question of how water canals should be designed to optimize boat speed. The children could vary the depth of the canal (shallow or deep), the shape of the boats (circle, square, or diamond cross section), the boat size (large or small), and boat weight (light, or unloaded, versus heavy, or loaded with a small barrel). The canal task was a try-and-see problem with an outcome easily interpretable as being more desirable. The buoyant problem required the children to investigate the effects of buoyant force on objects of different mass and volume. The children carried out experiments by varying variables in the system — object's volume (small, medium, and large); and mass (largest, intermediate, and smallest), and then measuring the extension of the spring with a ruler marked in centimeters. Half of the children began with the engineering problem and then went on to the science problem. The second half of the subjects started with the scientific problem and proceeded to the engineering problem. It was found that the subjects achieved the greatest improvement in strategic performance when they began with the canal task and then went on to the spring task. This, according to the authors, may be due to fact that this order may map more closely into children's natural way of thinking about scientific inquiry.

It is, of course, the aim of science teachers to lead students to possess the scientific model of inquiry. From the above discussion it may appear that the royal way to get children to reach the scientific model of inquiry is to first allow them to engage in activities that encourage them to utilize the engineering model. Such activities may be used as a kind of bridge which might help in decreasing the gap that novices might have between the two kinds of inquiry.



2. Technology-based science teaching is a natural learning environment utilizing cooperative learning. Most educators today will probably agree that cooperative learning should be implemented in the science classroom. This notion is well expressed in reform documents in education. For instance, *The National Science Education Standards* advocate for the use of small student learning groups:

> Using collaborative group structure, teachers encourage interdependency among group members, assisting students to work together in small groups so that all participate in sharing data and in developing group reports. Teachers also give groups opportunities to make presentations of their work and to engage with their classmates in explaining, clarifying, and justifying what they have learned. . . . In the hands of a skilled teacher, such group work leads students to recognize the expertise that different members of the group bring to each endeavor and the greater value of evidence and argument over personality and style. (National Research Council, 1996, p. 36)

Cooperative learning is founded on the belief that student-student discourse promotes cognitive growth and influences students' learning. This belief may be attributed to the *social constructivism* which views knowledge as a primarily cultural product (Vygotsky, 1978, in Windschitl, (2002)). Vygotsky viewed thinking as a characteristic not only of the child but of the "child-in-social-activities" (Moll, 1990, p. 12). Vygotsky's "zone of proximal development" emphasizes the importance of collaborative activities with the notion that the development of a child's mental functions must be fostered and assessed through the assistance of more knowledgeable others.

Based on the literature, Linn and Burbules (1993) suggest the following mechanisms that contribute to effective learning:

(a) Group learning motivates students to persist at a task.
(b) Group learning allows appropriation to occur when students build on someone else's idea to create an idea that they could not have generated alone through, for example, brainstorming.
(c) Group learning can draw on the distributed knowledge of all participants to locate ideas that help construct knowledge.
(d) Group learning provides the opportunity to compare ideas and construct a common point of view. Negotiation of meaning is the crux of the argument for the co-construction of knowledge.
(e) Group learning monitors the progress of students because the tutor or even other members of the group might cue students to check their work, compare solutions, generate self-explanations, or divide a problem into subparts. Furthermore, tutors often reduce memory demands for individuals by keeping track of progress, supplying details that otherwise would need looking up, and prompting helpful behaviors.
(f) Group learning members provide hints or feedback. Vygotsky, according to Linn and Burbules, argued that appropriate hints expand the zone of proximal development and scaffold students as they learn.
(g) Group learning enables the division of the task among group members. The "divide-and-conquer" approach reduces cognitive load for the group and allows the group to accomplish a more complex task.

In spite of the importance and value attributed to cooperative learning, schools attempt to minimize, if not eliminate peer interactions (Duran and Monereo, 2005).

In traditional science lessons, the creation of group tasks requires effort and knowledge. In my opinion, the teaching of science through design and technology activities occurs naturally in groups. When required to design and especially build simple machines, cooperation between students is needed. Students need one another's help when building an artifact. I argue that due to the nature of design and technology tasks, no special effort is necessary.

3. Learning by design utilizes the constructivist approach to learning constructivism. A theory and philosophy or learning that posits, as a result of interaction with the physical and social world, students individually and idiosyncratically construct scientific ideas and beliefs about the world before they receive formal instruction in class. Knowledge, according to constructivism, is always the result of a constructive activity and, therefore, cannot be transferred to a passive receiver.

> If we assume that students have to build up their own knowledge, we have to consider that they are not "blank slated." Even first graders have lived for a few years and found many viable ways of dealing with their experiential environment. The knowledge they have is the only basis on which they can build more. It is therefore crucial for the teacher to get some idea of where they are (what concepts they seem to have and how they relate them). (von Glaserfeld, 1993, pp. 32–33)

Based on a literature review, Windschitl (2002) suggests the following features of constructivist teaching which appear in the left column of the table. On the right column I explain why design and technology activities fit constructive features that appear on the left:

Features of constructivist teaching	**Reasons why the design and technology activities fit the features**
Teachers elicit students' ideas and experiences in relation to key topics and then fashion learning situations that help students elaborate on or restructure their current knowledge.	When raising ideas for designing simple machines students naturally express their own concepts. The evaluation stage of the student's artifact, especially if the artifact does not operate in the manner expected by the student, assists him or her to elaborate on and/or restructure his or her ideas.
Students are given frequent opportunities to engage in complex, meaningful, problem-based activities.	When designing an artifact the student is actually dealing with a real complex problem for which there is no right or perfect solution.
Teachers provide students with a variety of information resources as well as the tools (technological and conceptual) necessary to mediate learning.	The teacher might help the students with their designs by providing them with ideas, presenting similar artifacts to them, or teaching scientific principles relating to the behavior of the artifact.
Students work collaboratively and are given support to engage in task-oriented dialogue with one another.	Design and technology learning environments are natural environments which demand students' cooperation, for both designing and building the artifacts.

continued

Features of a constructivist teaching	**Reasons why the design and technology activities fit the features**
Teachers make their own thinking processes explicit to learners and encourage students to do the same through dialogue, writing, drawing, or other means of presentation.	First, designing involves the use of drawings. As mentioned before, due to the ability to refer to a concrete artifact, the discourse also includes the use of gestures in addition to words. This, I assume may contribute to the ability of the teacher to express ideas, which are, at least to some degree, explicit.
Students are routinely asked to apply knowledge in diverse and authentic contexts, to explain ideas, interpret texts, predict phenomena, and construct arguments based on evidence, rather than to focus exclusively on the acquisition of predetermined "right answers."	When students design and build artifacts they naturally have to apply their knowledge to the design problem which they are confronted. They, of course, have to predict the behavior of the designed artifact. They also need to evaluate their products based on how their artifact behaved and to suggest alternative solutions to the problems at hand. Of course, there is no right solution in such a problem.
Teachers encourage students' reflective and autonomous thinking in conjunction with the conditions listed above.	Teachers can easily ask students how and why they built their artifacts in the way they did. Did the artifact indeed behave as planned. How did they improve it and why, etc. These kinds of questions may encourage students to reflect on their designed products.
Teachers employ a variety of assessment strategies to understand how students' ideas are evolving and to give feedback on the processes as well as the products of their thoughts.	The artifact itself with the explanation of its behavior, as well as the related scientific rules might provide the teacher with another assessment tool which is currently not accepted by science teachers.

4. *Technology-based teaching promotes question posing*. In his book, *The Disciplined Mind — What All Students Should Understand*, Howard Gardner (1999) writes "On my educational landscape, questions are more important than answers and more important, understanding should evolve from the constant probing of such questions" (p. 24). However, one interesting question is, who's questions should we engage our students with? Brown and Walter (1990) write in their book, *The Art of Problem Posing*,

> Where do problems come from, and what do we do with them once we have them? The impression we get in much of schooling is that they come from textbooks or from teachers, and that the obvious task of the student is to solve them. (p. 1)

Brown and Walter (1990) call for "a shift of control from 'others' to oneself in the posing of problems . . ." (p. 1). They claim that problem posing can help students to see a standard topic in a new light, along with providing them with a deeper understanding of it. They also quote a phrase which, to their opinion, well demonstrates a deep appreciation for the role of problem generating from Chaim Potok's novel *In the beginning*:

> I want to tell you something my brother David, may he rest in peace, once said to me. He said it is as important to learn the important questions as it is the important answers. It is especially important to learn the questions to which there may not be good answers. (Chaim Potok, in Brown and Walter, 1990, p. 3)

The importance of question posing dates back to Socrates who wrote "so you will make a law that they must devote themselves especially to the technique of asking and answering questions . . ." (Socrates, in Dillon, 1990, p. 7). This is probably because the ability to pose questions is associated with high order thinking. This is well expressed in the following citation,

> Good thinkers are good questioners, taking enjoyment in being doubtful and suspicious of their world, in a positive sense. They take advantage of uncertainty. Why is the world so? Why must it be so? Are other views possible? What other answers might be plausible? Good thinkers utilize questions in particular ways to get at deeper rather than surface meaning. (Hunkins, 1989, p. 15)

Questions, which are essential education tools for all disciplines in general, are of crucial importance in science (Dori and Herscovitz, 1999). As Orr (1999) says, "Good science demands two things: that you ask the right questions and that you get the right answers. Although science education focuses almost exclusively on the second task, a good case can be made that the first is both the harder and the more important" (p. 343). Indeed, the idea of question posing stands at the heart of inquiry-based science teaching. Joseph Schwab (Schwab *et al.*, 1962) who articulated the concept of inquiry-based teaching quite well, envisioned a school curriculum that gave a more accurate representation of the scientific endeavor by practicing scientists, including *active questioning* and investigation. Today, with inquiry-based pedagogy becoming more central with the call of the National Science Education Standards (NRC) that inquiry be a "central strategy for teaching science" (NRC, 1996, p. 31), being aware of children's abilities to ask questions is notably increasing. According to this NRC call, students should learn, among other skills, how to pose a scientific question and to identify and conduct procedures to answer the question. One reason for encouraging and promoting inquiry-based teaching is that children express positive attitudes towards inquiry. Students like to be involved in asking their own questions and formulating ways to answer those questions (Crawford *et al.*, 1999; Gibson and Chase, 2002; Hand *et al.*, 2004).

Despite the importance of children learning to ask their own questions, Dillon, in *The Practice of Questioning* says that children everywhere are schooled to become masters at answering questions and remain novices at asking them. One reason is that teachers are not, unfortunately, properly prepared to teach students how to ask questions. One possible solution from educational researchers, is to offer suitable learning environments to the teachers: environments where children are naturally encouraged to ask questions. I argue that such an environment is the *learning through technology* class. When children design artifacts they naturally start to ask "what if" questions. In addition, when they try out the designs that they build, they naturally start asking "Why doesn't it work?" "How can I improve it?" "Why did the other group's artifact work better?" "What is the scientific explanation for this difference?"

5. Technology-based teaching promotes systematic thinking. According to Senge (1990) system thinking is a school of thought that focuses on recognizing the interactions between the parts of a system and then synthesizes them into a unified view of the whole. Furthermore, it deals with recognizing patterns and interrelationships, while learning how to structure those interrelationships into more effective, efficient ways of thinking.

Based on literature review, Ben-Zvi Assraf and Orion (2005), recognize eight characteristics of system thinking:

a) The ability to identify the components of a system and process within this system.
b) The ability to identify relationships among the system's components.
c) The ability to organize the system's components and processes within a framework of relationships.
d) The ability to make generalizations.
e) The ability to identify dynamic relationships within the system.
f) The ability to understand the hidden dimensions of the system.
g) The ability to understand the cyclic natures of systems.
h) The ability to think temporally: retrospection and prediction.

It is important to understand two points: (1) the above attributes of system thinking are not independent of one another, so there may be some degree of redundancy between them, and (2) these characteristics are not necessarily comprehensive.

When trying to recognize system thinking one should not necessarily expect to find all of the above attributes in a given system.

De Vries (2005) points out that the concept of a system can be a strong educational 'tool' to teach about artifacts. According to the author, by making system diagrams of an artifact, its parts (sub-systems) and the way they are connected, pupils and students can gain a first impression of the physical and the functional nature of the artifact. I agree that understanding the concept of a system may help children and older students to understand the artifacts they are dealing with. Learning about artifacts may also help students gain a better insight as to what a system is. This is very important due to the difficulties with which all students of all ages are faced with when dealing with the complexity of a system. For instance, Hmelo, Holton, and Kolodner (2000) found that sixth graders had problems understanding the human respiratory system, partially because they had difficulty understanding the macroscopic as well as the microscopic levels of the entire system. Moreover, they indicated that it is impossible to understand these systems at different levels without understanding the function of the entire system. Kali *et al.* (2003) also reported on students' difficulties in developing system thinking about the rock cycle. It appears that in order to understand how trees function in the forest, it is not enough to understand each tree separately, but rather, to understand how the whole forest functions. Equipping children with systematic thinking, therefore, might help them tremendously with understanding of scientific as well as technological systems. By engaging students with artifacts and encouraging them to deal with questions relating to the operation of the artifact in a system may promote system thinking within children. To achieve this goal, the teacher should expose children to questions such as: What parts make the artifact? Are there any hidden parts? Why are they hidden? How is the function of part 'x' influenced by the function of part 'y'? What will happen if we switch between part 'x' and part 'y'? How will the system behave if only part 'x' is broken?

6. Technology-based teaching encourages the use of thought experiments. In the following, I show that the process of design is associated with thought experiment. Thought experiments, even though entirely the products of mental activity, are viewed as empirical experiments that either cannot or have not been executed empirically,

> A thought experiment is an experiment that purports to achieve its aims without the benefit of execution. (Sorensen, 1992, p. 205)

Thought experiments, according to Gilbert and Reiner (2000), "play a major . . . role in science education both by facilitating conceptual change and in relation to some types of practical work" (p. 266). If thought experiments do contribute children's conceptual change, then educators should encourage their students to execute them.

It is my view that thought experiments are crucial in designing tasks. This view is based on the idea that "conceptual construction starts by negotiating meaning, with self and with others, through 'what-if' questions that turn into imaginary experiments in thought, ultimately being applied to the original physical situation" (Reiner and Gilbert, 2004, p. 1821). The following two examples clarify this point:

Example 1: The Parachute Task

In a study examining middle school students learn physics concepts through engagement with simple models, the students were given, among other things, the following design task: "Fill a plastic cap with sand. Now, in groups, design a parachute that will carry the weight so that it reaches the ground in the longest time possible when it is released from a height of 2-meters." The students started to ask questions such as, "What if we had two or even three parachutes instead of one"; "What if we had a big/small parachute"? What if the ropes connecting the plastic cup to the parachute were short/long? From the students' answers it seems as if they ran TEs. The following paragraph is taken from an interview with a student just after he and his team completed building the parachute that they designed:

Interviewer: What did you build?

Student: It is a very novel parachute. It has two covers.

Interviewer: Why do you think this might be a good parachute?

Student: I don't know. I guess it will fall slower. I thought that if with one cover it (the parachute) falls slowly . . . I hypothesize that with two covers it will fall even slower. You see, there are two places that the air can get in [points with his fingers to the upper cover and then to the lower cover and raises his fingers]. The air applies a larger force because it comes in contact with the two covers [the student, again, raises his fingers upwards].

Example 2: The Hot Air Balloon Task

In another task the students were asked to design a hot-air balloon which would achieve the greatest height. A group of students started to work and decided to make a cube shaped air balloon. From what they said to one another it seemed as if they were looking for a symmetric shape. While the group worked, one student sat a bit further off from the group and stared at the sheets of papers which were on the floor. After a while he said:

> We need to change the shape of the balloon. It should be extended. [the student meant that the box should be rectangular and not a cubic].
>
> Other student asked him: Why?
>
> The student answered,
>
> At the beginning I thought we needed to make a cubic shape so that we'd get a symmetric shape. But, if it was cubic, the hot air would escape faster from the balloon. If we have an extended box the hot air will have more space to go up and it will lift the balloon up. Also, it will not escape the balloon as fast as in the case of the cubic balloon.

The two paragraphs contain explanations of the designs that the students created. Both explanations are based on concrete details that one can easily use to construct visual representations in his or her head and run mental experiment to test the hypothesis.

In the first description you can easily construct an image of a falling parachute consisting of two covers. You can even "imagine" the air touching the two covers and slowing the parachute down. This, of course, can not be done in reality, since air is invisible. In the second interview concerning the hot air balloon, you can easily imagine an airborne box. The box contains hot air which fills the upper portion of the balloon. Whether or not they are scientifically correct, the children's explanations are very imaginable. This may justify the hypothesis that children may have run experiments in their heads which helped them to test their hypotheses. Based on the results of their TEs they could therein build their parachutes or balloon models. In addition, the students used gestures to clarify their explanations. This too might support the hypothesis that students ran experiments in their heads to test their explanations. Indeed, according to Clement (1994) depictive hand motions are indicators for determining the occurrence of imagistic simulation. From this discussion one may conclude that science teachers may use design activities in their classes, which may encourage their students to run TEs which, in turn, will contribute to the understanding of the relevant scientific concepts.

7. Technology-based science teaching promotes creativity. Although the concept of creativity is an elusive one to define (Hu and Adey, 2002), it is agreed that creativity has a connotation of originality, which may be characterized by novelty, difference, ingeniousness, unexpectedness, or inventiveness (Glover *et al.*, 1989). Sternberg and Lubart (1999), define creativity as "the ability to produce work that is both novel (i.e. original, unexpected) and appropriate (i.e. adaptive concerning task constraints)" (p. 3). According to Boden (1999) novelty may be defined with reference to either the previous ideas of the individuals concerned or to the entire human history. Pope

(2005) argues that this allows for someone to make a discovery or experience a personal break-through (what Boden calls ‘P-creative’, new to the person), even though it may already be known or have been known at some part in time (in Boden’s terms — ‘H-creative’, new in history). The idea of being creative in reference to oneself has an important role in education since the aim of educators is to encourage and promote creativity within students. Designing, by nature, is described in the following citation, involves innovation of new ideas and transferring them into artifacts.

> Engineering design has been defined as, the transformation of ideas and knowledge into a description or artefact, in order to satisfy a set of identified needs; it is the key technical ingredient in producing new products governing the match between products and actual requirements. (Cripps and Smith, 1993, in Court, 1998, p. 143)

In a similar manner, design and technology curricula require school students to generate new ideas, analyze them, make a selection, and describe their artifacts by using verbal and non-verbal representation. Their artifacts should, of course, satisfy a set of requirements. It is thus my understanding, that teaching science through designing may encourage their scientific creativity. Support to the connection of technology and design skills in creativity are items no. 3 and 7 from a *Scientific Creativity Test for Secondary School Students*, developed lately by Hu and Adey (2002):

> *Item 3*
>
> Please think up as many possible improvements as you can to a regular bicycle, making it more interesting, more useful and more beautiful. *For example, make the tyres reflective, so that they can be seen in the dark.*
>
> *Item 7*
>
> Please design an apple picking machine. Draw a picture, point out the name and function of each part.

According to the authors, this task is designed to measure creative science product design ability.

It is also important to mention that when creative students are taught and their achievements assessed in a way that evaluates their creative abilities, an improvement in their academic performance is noted (Sternberg *et al.*, 1996). Thus, by evaluating their artifacts, students may also gain in achievements and understanding of the science topics. Given the chance to be creative, students who might otherwise lose interest in school instruction, might find that it captures their interest instead (Sternberg, 1999). This is very important, especially in science, which suffers some children’s lack of interest. To summarize, it is my view that teaching science through design and technology may be a good idea for improving students’ creativity as well as their interest and achievements in science.

8. Technology-based teaching involves bodily knowledge and gestures. I started this chapter by describing the idea of *learning by doing*. I also presented several theories supporting this idea. There is another facet of *learning by doing*. When we *do*, we gain *Bodily knowledge*, which is the kind of knowledge reflected in motor and kinesthetic acts (Reiner and Gilbert, 2000). This knowledge is “stored” in our body and impacts our learning processes. For instance, Clement (1988) showed that embodied intuitions about forces have a role in understanding physics situations. He suggests that knowledge embodied in perceptual motor intuitions is used by experts for physics problem solving. Druyan's work also supports the idea that efficient kinesthetic experiences like jumping training, or measured walking with peers, might help children gain a better understanding of the concept of length. 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). In an interesting paper, *Learning With Real Machines or Diagrams: Application of Knowledge to Real-world Problems* (Ferguson and Hegarty, 1995), the authors investigated how learning either from real pulley systems or from simple line diagrams, affected university students' ability to:

a) compare pulley system efficiency;
b) understand mechanical systems; and
c) apply their knowledge to real-world mechanics problems.

In the first experiment there were two learning conditions:

- i. Hands-on real condition: The subjects learned by interacting with real pulley systems — they viewed a pair of real pulley systems and acquired information on the system's relative efficiency by actually pulling on the free ends of the ropes.
- ii. Diagram condition: subjects learned by viewing diagrams and acquiring information verbally about the efficiency of the systems.

In the second experiment, the authors introduced another condition, the static-real condition. In this condition subjects saw the details of the pulley system configuration but did not observe the motion of the system or experience the weight differences kinesthetically. The experiments showed that subjects who learned hands-on, by manipulating real pulley systems, solved application problems more accurately than those who learned from diagrams. The second experiment showed that it was both the realism of the stimuli and the opportunity to manipulate systems which contributed to this improved performance on the application problems. If the kinesthetic body knowledge contributed to university students' understanding of the physics concepts, for children who most certainly possess lower cognitive abilities at this stage of their life, body knowledge might have an even greater impact on their concept construction. Design and technology activities provide a contact between the child's body and the system. By manipulating the system the child may feel forces, hear, see and smell. This non-verbal knowledge assists the child in gaining a better understanding of the underlying scientific principles fundamental to the system's behavior.

Examples of artifact based science teaching activities

The following examples are of tasks performed both with children and teachers. The results were very similar, but, because the session with the children was not documented, these examples are from the group of teachers.

1. The air car. The first stage consists of presenting the children with an example of a simple air powered car made of two straws connected together and a balloon attached to the end of one of them. Two wheels are attached on the two ends of the straw perpendicular to the one with the balloon, as is shown in Fig. 3.

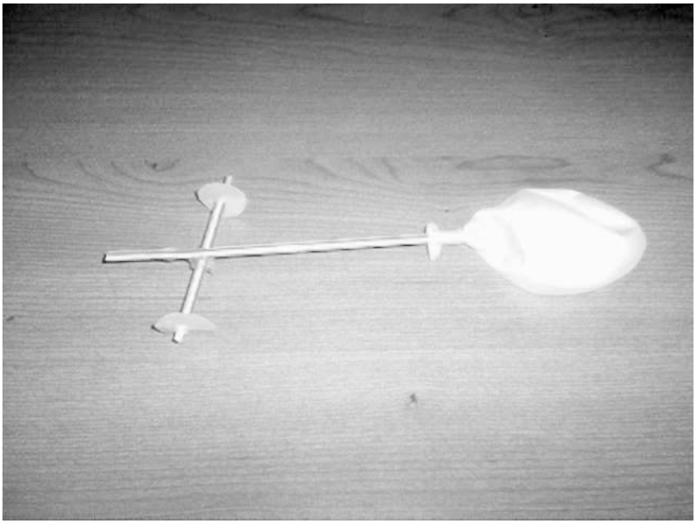


Figure 3. Simple model of air propelled balloon car.

The children are asked what they think the artifact does. The children, seeing wheels on the artifact, will more than likely associate the possibility of movement. They see a balloon and say that it can be inflated. The children can then be asked what they think will happen after the balloon is inflated. Some of the children will then say that it will move much like a car and some may say that it will fly into the air. The children are then asked as to the direction of the movement, supposing it was to move on the ground or in the air.

The children can then take a shot at inflating the balloon and letting it go, observing the movement of the car in the opposite direction of the direction of the air coming out of the balloon.

The concepts which can be learned here are: The balloon is elastic in nature and as a result of it contracting, pushes out the air; the air moves in one direction (the children can try feeling the air flowing out of the balloon) and the car in the complete opposite direction. This is definitely a superb introduction to the teaching of Newton's third law (The balloon pushes the air, which as a result pushes the balloon and with it the car).

The second stage consists of having the children try and improve on the original model. The children can be asked to create a faster car than the one shown to them by the teacher. This, of course encourages work in groups because the children are asked to build something, which is always easier done with the help of another person than by oneself. The children are trying to deal with an open problem where there is no one correct answer. There can be many different approaches to it, all plausible and more than likely to achieve the required goal (the making of a faster model). This opens the door for creativity among the children and allows them to express and use previously acquired knowledge. They can immediately test their ideas as they come to mind, which also encourages question asking: "Why does it move like that", "Why is it like this?"

The following are examples of refinements made during sessions with children and teachers alike:

a) One group decided to make an axis independent from the main body of the car, meaning that it was able to spin freely. This was done by connecting the wheels to the straw perpendicular to the main straw by use of a toothpick (which could rotate freely inside the straw), thus allowing the car wheels to turn with the propagation of the car. The idea of changing the axis from one that was fixed to the body to one that was more free, led to a discussion on the axis and its function. A discussion also arose on the difference between wheel friction and slipping friction.

b) Another group decided that raising the balloon from the ground (as shown in Fig. 4) by placing it on top of a small water bottle or an aspirin box, would allow for less friction with the floor and therefore also for an increase in velocity. The participants did not limit themselves to the materials shown on the original artifact, but rather chose creative ways of building their artifact using a variety of materials like foamed plastic for wheels or even wheels made of rolls of string, as is shown on Fig. 4.

c) A common factor chosen to increase the velocity of the car, was the number of balloons connected to it. Many of the groups decided to increase the number of balloons from one balloon to two. A discussion was then held on the reasons leading to the increased velocity as a result of adding more balloons, such as increased force and power caused by the balloons. This encouraged a discussion on friction (see Fig. 5).

d) Some of the participants decided that changing the wheels to a smoother material would somehow help increase the velocity of the car. This was particularly interesting as it led to another discussion on the use of the axis — this factor would indeed have a positive effect if there was no unrestrained axis, however much less of an effect when one was present.

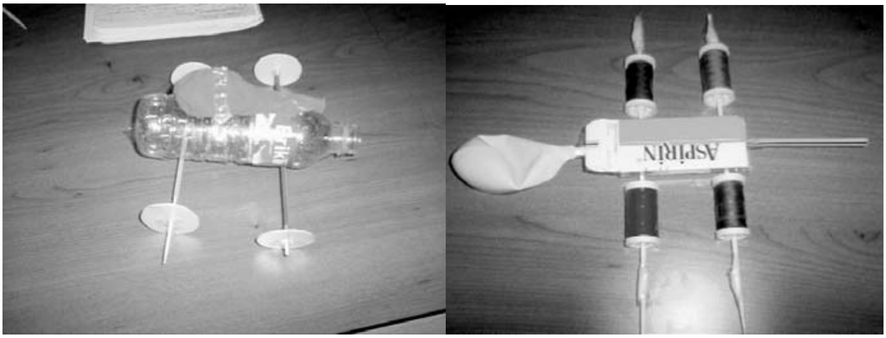


Figure 4. Car design with balloon raised from the ground.

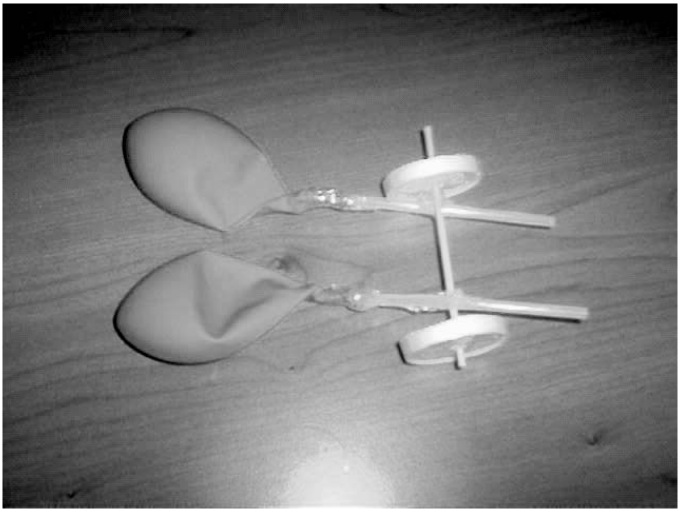


Figure 5. Car design with two balloon for increased propulsion.

e) One especially interesting group decided for some reason to add extra wheels which were not parallel to the original wheels (as shown in Fig. 6). This caused an opposite effect to that which was desired, raising a large number of questions as to why this happened, why it is in fact that when the 2 wheel axis's cross each other they interfere with the cars movement. It also lit up a discussion on how more is not necessarily always better.

2. The parachute. This example was performed on groups of junior high school students. In this example, as was stated earlier in this chapter, the children were shown a simple parachute made of some cloth and strings. Attached to it is a weight of some sort.

The groups were then asked to create a parachute, which takes the longest time to fall, when released from a predetermined height. All the parachutes are given the exact same weights.

The groups try different methods in order to reach the goal, some efficient while others less. Some groups altered the size of the cloth or even tried creating parachutes with two cloths, while others experimented with the impact of different string lengths connecting the cloth.

One group had the misconception that the air slowing the parachute's descent was in the shape of a "pocket." They thought that if they could hold this "air pocket" they would be able to get a considerable increase in the parachute's effectiveness. To do this they decided to take two cloths and place them one on top of another, while making a small hole in the bottom cloth. They hoped that by doing this, the air would go through the first cloth and become entrapped between the two cloths, therefore slowing the parachute considerably. Needless to say, this experiment was a failure and the

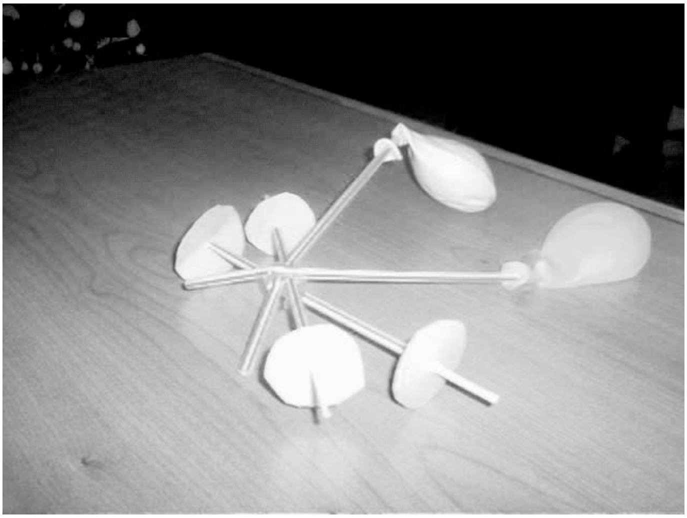


Figure 6. Car design with two axis's not parallel to one another.

parachute simply plummeted to the ground. This caused the children to start asking questions as to what caused the parachute to fall so fast and why their experiment failed to succeed.

After all of the groups had finished creating their parachutes, everyone gathered around and discussed which of the parachutes would take the longest time and why. After testing all of the parachutes and gathering the results, another discussion was held as to why some aspects affected the speed of descent more than others. Discussions concerning the force applied to the cloth by the air and how it enables the parachute to slow the descent of the weight. Through this discussion came a discussion on lift force and how it effects the parachute's descent, along with a general discussion on velocity. The effect of different weights, although not tested in the session itself is also discussed and demonstrated.

DISCUSSION

Lee and Songer (2003) argue that even though science has been part of the school curriculum since the turn of the 20th century, there is still controversy as to how school science should be taught in order to deliver the essence of science to students. Moreover, I believe, that educators still struggle with developing teaching methods suitable to children's needs and desires. The aim of this chapter was to discuss the potential that design and technology activities might have in implementing the *learning by doing* approach, hence increasing motivation among the children and their willingness to learn and understand scientific concepts. I started the chapter by describing the notion of learning by doing and explaining how that is supported by the case-based reasoning as well as situated learning theories. I then claimed that though schools make enormous efforts to utilize the *learning by doing* idea, they usually miss the heart of the idea and may in fact detach doing from any meaningful learning. This situation leads to *activity-mania*. There are two reasons for the inefficient implementation of the *learning by doing* approach. The first is the lack of awareness by teachers of the effects that *learning by doing* has on children. The second reason is that teachers themselves lack the knowledge to actually perform *learning by doing*. The present chapter presented the notion that design and technology activities are good vessels for implementing the *learning by doing* approach. This notion relies on the strong association between technology and doing. The following quotation emphasizes this association even further:

> Technology is the practical method which has enabled us to raise ourselves above the animals and to create not only our habitats, our food supply, our comfort and our means of health, travel and communication, but also our arts — painting, sculpture, music and literature. These are the results of human capability for action. They do not come about by mere academic study, wishful thinking or speculation. Technology has always been called upon when practical solutions to problems have been called for. Technology is thus an essential part of human culture because it is concerned with the achievement of a wide range of human purposes. (Black and Harrison, 1992, pp. 51–52)

This association, as well as the idea that the time spent by young children at preschool and early primary school is heavily marked by activity and involves the interaction between the children and physical objects around them, led me to pursue a thorough explanation as to why and whether design and technology may be used to teach science. I came up with the following eight reasons:

1. Children tend to employ engineering models of inquiry rather than scientific models.
2. Technology-based science teaching is a natural learning environment utilizing cooperative learning.
3. Learning by design utilizes the constructivist approach to learning.
4. Technology-based teaching promotes question posing.
5. Technology-based teaching promotes systematic thinking.
6. Technology-based teaching encourages the use of thought experiments.
7. Technology-based science teaching promotes creativity.
8. Technology-based teaching involves bodily knowledge and gestures.

I assume that the above reasons are not the only ones and that the reader may think of other reasons as well. I do hope, however, that these reasons alone will convince the reader that there might be a strong power in teaching science through design and technology. In addition, the chapter provided some examples to help those who may be interested in joining this adventure and progressing it from theory to action.

As was suggested here, I believe that teaching science via technology also helps in overcoming the problem that Edelson (2002) raised regarding the difficulty in making authentic real-world science accessible to children. The author argues that authentic activities that are interesting to students are too open-ended, and require knowledge content and scientific thinking of which students do not necessarily have the base and the means to comprehend. The design and technology activities may, in my opinion, be considered a real-world activity which the child may, with suitable teaching, be able to handle, and that may promote the understanding of scientific concepts.

This chapter dealt with one direction — the use of technology in science. Another interesting question is the one I deal with in the following section.

Should we integrate Science, Design and Technology?

I already mentioned the problem with the design and technology curriculum, in which children that learn technology may become disconnected from the science curriculum. Indeed, according to Barlex and Pitt (2002) there is scant communication between staff in the science and design and technology departments and topics which arise in both curricula may be taught in both subject areas with no connections being made by either teachers or students. This situation, according to the authors, leads to wasted time and the loss of valuable opportunities for enriching children's learning. I also previously argued that by doing so we do not implement the idea that science and technology are part of a seamless web that integrates any distinction. In an effort to try and fix the situation, I herein suggested that the sciences should include design and technology. This approach should, of course, be implemented on top of other methods. One question, which, in light of what has been argued in this chapter, may bother the reader, is whether science, design and technology should be integrated. This is beyond the scope of the current chapter. I only wanted to show that the use of design and technology activities within the science topics has enormous potential in implementing science learning by doing and make science lessons more efficient. I do, however, want to close the chapter by referring to this dilemma. By taking the web-less view into account it might look natural to integrate the two subjects. However, one should seriously consider the argument that Barlex and Pitt (2002) make, according to which integrating science, design and technology is inappropriate. The authors claim that,

> science and design and technology are so significantly different from one another that to subsume them under a 'science and technology' label is both illogical and highly dangerous to the education of pupils. Both are necessary and from their individual positions can enhance each other. Science is essentially explanatory in nature whereas design and technology is aspirational . . . . Design and technology is the area of the curriculum that enables students to intervene creativity to improve the made world. As such it is essential that design and technology is neither deflected from this main purpose nor diluted in its effectiveness by a shotgun marriage. (p. 189)

Does Barlex and Pitt's view contradict the seamless web view? No. It is my understanding that the connection between science and technology can indeed be seen as having a kind of web-structure. However, even in this web one can recognize the technological parts and distinguish them from the scientific parts and vice versa. Although I would avoid using terms such as *illogical* and *highly dangerous*, I agree that integrating the two might cause us to omit some important aspects of each topic. Thus, it is my opinion that each of the subjects should develop its own activities with regards to the other. I suggested that science can develop more design and technology activities which are relevant to science lessons and, on the other hand I also suggested that design and technology might develop scientific activities. In addition, as was also suggested by Barlex and Pitt (2002) I suggested that designers of each topic be aware of the other topic's curriculum so that a better match can be achieved between the two. To summarize my suggestion it might be worthwhile to think of it as islands of technology within the science lessons and as islands of science within the design and technology subjects. The teacher's role would then be to build bridges so that the child can first move securely between the islands and as a result will construct web structured relationships for him or herself.